The Journal of Bone and Joint Surgery*

American Volume

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April 1948

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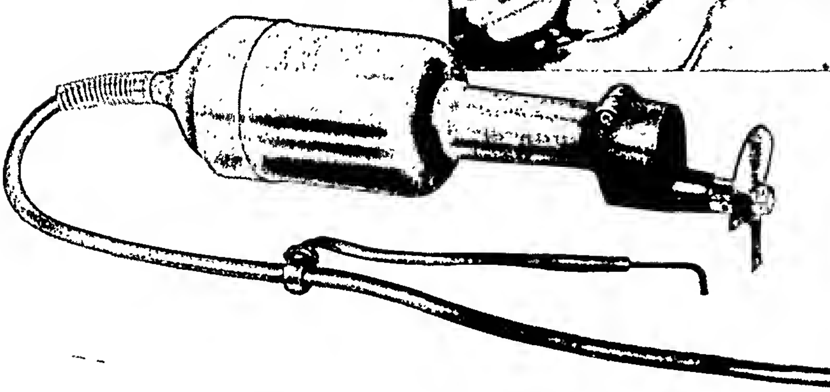

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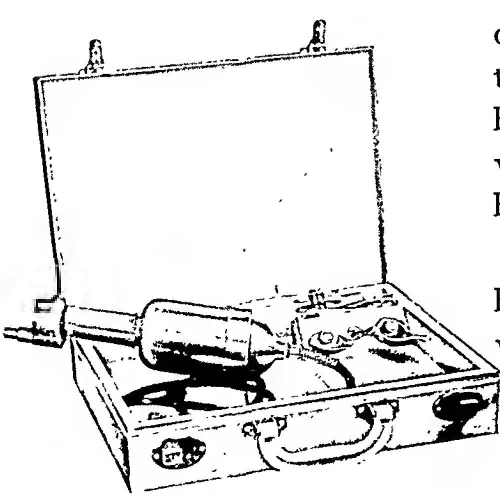

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The Australian Orthopaedic Association
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EDITORIAL

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The British Volume will be representative of orthopaedic surgery in the British Commonwealth of Nations; the American Volume, of the United States of America. From all nations, articles contributing to the development of the specialty will be welcome.

The trend of policy that has led to the present plan is suggested by a glance into the past. *The Journal* originated in 1889 as the *Transactions of The American Orthopaedic Association.* In 1903, it became national in scope and was called *The American Journal of Orthopaedic Surgery.* During the war years, 1914 to 1918, the accomplishment of many British and American surgeons, working together under the guidance of Sir Robert Jones, had been outstanding. Joint publication of *The Journal* offered a means of continuing the cooperation. In 1919, *The American Journal of Orthopaedic Surgery* became the official organ of The British Orthopaedic Association. Greater benefit to the orthopaedic surgery of each country was anticipated from the interchange of ideas through a common publication. To signalize the broader aim, the name became *The Journal of Orthopaedic Surgery.* Later, the name was changed to *The Journal of Bone and Joint Surgery.*

Thirty years ago, the growth of medicine had become rapid. With expansion came the development of all branches of medicine and surgery. In 1922, orthopaedic surgery was becoming established as a specialty. At that time The American Orthopaedic Association extended the scope of *The Journal* by including articles representative of diverse viewpoints throughout the world. That year, Dr. E. G. Brackett became the Editor of *The Journal.* During the twenty years of his editorship, Dr. Brackett built *The Journal* that we know today. Always the development of its international character was uppermost in his mind. The surgery of any land may reach its highest attainment through the free interchange of ideas from widely scattered sources; surgery, like pure science, belongs to the world.

The Journal has grown as the need for ampler expression has increased. The importance of further expansion has become evident. In many countries, orthopaedic surgery has reached a high degree of development. Freer expression of national trends has become necessary. Increased space has been needed for articles from all countries. Orthopaedic surgeons in Great Britain and in America have had to decide whether the best interests of the surgery of their countries lay in separate or in cooperative publication.

In the spring of 1947, representatives of The American Orthopaedic Association, The British Orthopaedic Association, and The American Academy of Orthopaedic Surgeons met in London to formulate plans to continue the long association and at the same time more fully meet the growing needs of the specialty. From their recommendations came the new plan of publication under which *The Journal* now appears.

With belief in the wisdom of the new plan and confident of the support of surgeons everywhere, the Editorial Boards will endeavor to uphold the standards of *The Journal* and to maintain its aim,—the advancement of orthopaedic surgery.

William A. Rogers

THE MECHANISM AND TREATMENT OF FRACTURES OF THE CALCANEUS

Open Reduction with the Use of Cancellous Grafts

BY IVAR PALMER, M.D., STOCKHOLM, SWEDEN

From Södersjukhuset, Stockholm

Many details of the mechanism and pathological anatomy of fractures of the calcaneus are unknown. The complex structure and anatomical relationships of the calcaneus have made it difficult to clarify the exact nature of these fractures. The roentgenograms are not easily interpreted and often tell only part of the truth. Certain aspects of these fractures are better understood, however, when observed against a background of experience gained by surgical exposure of the fragments.

MECHANISM OF INJURY

The usual explanation of the mechanism of fractures of the calcaneus is that a fall from a height causes the talus, which constitutes the wedgelike pinnacle of the longitudinal arch, to be driven down upon and to break the calcaneus, which forms the large posterior foundation of the arch. This sketchy explanation may be correct in certain fractures of the calcaneus; it throws little light, however, upon the exact nature of the injury. The problem may be simplified by regarding each fracture of the calcaneus as a linear fracture of one of three types,—avulsion, compression, or shearing. Shearing fractures are caused by the simultaneous action of two adjacent, but opposed, parallel forces. In a fall, the part of the tuber calcanei which first strikes the ground is forced upward by

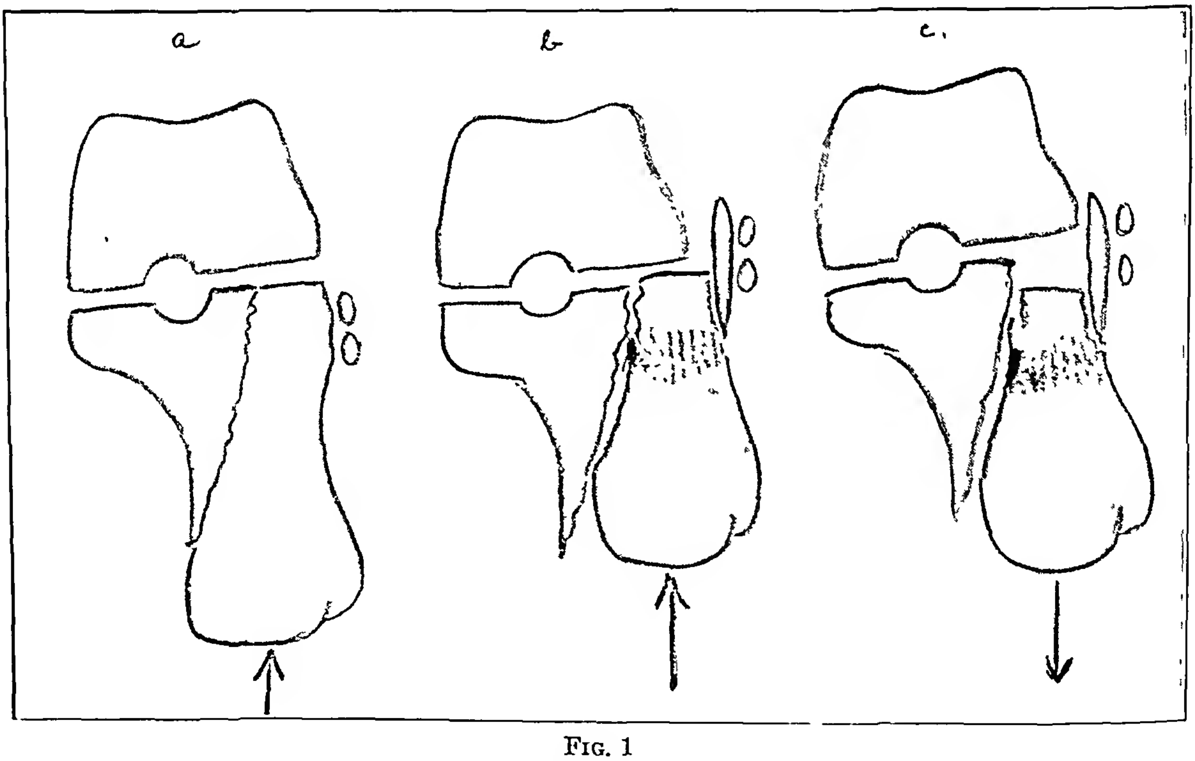

Fig. 1

Diagram showing the mechanism of comminuted fractures of the calcaneus.
a: Primary shearing fracture.
b: Compression and maximum dislocation at the moment of accident.
c: The lateral block, with impacted fragment due to secondary compression, recoils downward, forming a ledge across the surface of the joint.

the impact, while the articular portion is driven downward by the talus; the result is a vertical shearing fracture. If the foot is in varus position as it strikes the ground, a medial chip will be split from the tuber; if the foot is in valgus position, a lateral fragment will result. The medial type is infrequent, constituting, according to Watson-Jones, only 15 per cent. of all fractures of the calcaneus. The lateral type, which usually involves a large part of the tuber calcanei, has an incidence of about 25 per cent. The fragments are displaced forward and upward, in accordance with the direction of the causative violence. If the fragment of the tuber is large enough, the result will be a simultaneous compression and depression of the longitudinal arch. The depression may be indicated by the so-called "tuber-joint angle" of Böhler, which has been generally accepted as a standard for the evaluation of all fractures of the calcaneus. These two simple fractures offer no problems in mechanism or treatment. Their prognosis is favorable.

In most cases of lateral shearing fracture, however, the injury is not restricted to the tuber. The line of fracture starts from the medial side and runs laterally and upward; failing to reach the lateral surface of the tuber below the posterior facet of the talocalcaneal joint, it extends upward through the floor of the joint and splits it into two parts (Fig. 1, *a*). Sometimes the fracture line continues forward to split the calcaneocuboid joint also. This type of shearing fracture is, therefore, intra-articular. Although it comprises the largest group (at least 50 per cent.) of all fractures of the calcaneus, the details of its structural relationships are little known. Roentgenograms fail to show clearly and completely its most important characteristic,—the intra-articular involvement. Its prognosis is unfavorable. Most patients who have sustained this type of fracture have a permanent disability of from 25 to 33⅓ per cent.

These observations led the author a few years ago to attempt to treat this type of fracture by arthrodesis of the subtalar joint. It was thought that arthrodesis would reduce the healing time and put the foot into a position in which it might be capable of bearing weight without becoming painful. These operations provided an opportunity of studying the structural details of the fracture, and led to certain observations which have been verified subsequently in a considerable number of cases.

The large fragment produced by lateral shearing was found to be separated from the medial, undisplaced portion by a fracture line which ran longitudinally through the posterior facet of the talocalcaneal joint, dividing its articular surface in such manner that at least half of it was on the lateral fragment. Within this large lateral fragment, however, an additional or secondary fracture of compression type was found, the articular surface and underlying bone having been driven down into the subjacent spongy bone. This assembly of the lateral block was often covered laterally by a small shell-like fragment of cortical bone. A strange and interesting fact, moreover, was that the extent of the compression of the articular fragment not only corresponded to the forward and upward displacement of the lateral block, but even exceeded it in depth. This created in the joint a *ledge*, which sometimes reached the height of about 10 millimeters. Moreover, the planes of the two portions of the fractured facet were as a rule not parallel, the ledge being higher in front than at the rear. The articular fragment was clearly outlined, with no sign of being crushed into the smaller fragments which are seen in other compression fractures, such as those of the lateral condyle of the tibia.

The mechanism underlying this extremely important feature of the topography of the fracture seemed mysterious. It was at first thought that the talus, at the moment of the accident, had been subluxated over the calcaneus and thereby exerted an uneven pressure, which was greater laterally than medially. However, this hypothesis was abandoned, because it did not explain the sharply outlined ledge within the joint.

Little by little the following explanation of the mechanism of fracture became apparent. As the lateral block is pushed forward and upward by the dislocating force, it meets the resistance of the posterior articular facet of the talus. Cartilage is driven vio-

lently against cartilage. If the force is great enough, the weaker part, which is the more mobile lateral fragment of the calcaneus with its smaller surface, is pressed together like a concertina. This compression corresponds exactly with the displacement of the heel, when it reaches its maximum at the time of the accident (Fig. 1,*b*). When the compressing force ceases, the lateral block recoils slightly; in addition, it is displaced by contraction of the Achilles tendon. The articular fragment, which has been pressed firmly into the underlying bone, follows the recoil in a direction opposite to that of the original compressing force. Its contact with the articular surface of the talus is lost, and the sharp ledge of the undisplaced articular surface of the medial calcaneal fragment is produced (Fig. 1,*c*).

Further observation showed that the secondary compression fracture of the lateral block was of two types:

1. In some cases the articular fragment was about 1.3 centimeters in height and equal to the articular surface in length (Figs. 2-A and 2-B). This fragment, impacted more or less deeply into the subjacent bone, consisted in itself of a well-defined, unbroken piece of bone, covered on its articular surface by intact cartilage. A separate shell-like

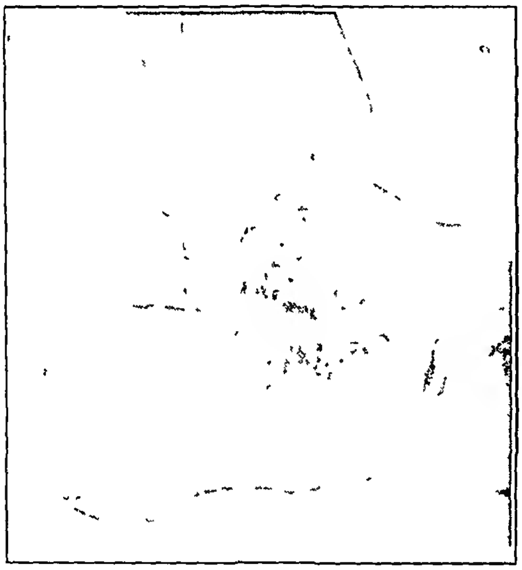

Fig. 2-A

Fig. 2-B

Fig. 2-A: Comminuted fracture, Type I, before reduction.
Fig. 2-B: After open reduction and filling with cancellous graft.

Fig. 3-A

Fig. 3-B

Fig. 3-A: Comminuted fracture, Type II, before reduction.
Fig. 3-B: After open reduction and filling with cancellous graft.

fragment of the lateral cortex, attached to the sheath of the peroneal tendons, was often present.

2. Just as often, however, the upper fragment extended posteriorly to include the upper part of the tuber; the tuber was thereby split into two portions, which gaped apart posteriorly. Fractures of this type proved particularly convenient for treatment by open reduction, because of the size and shape of the fragment which supported the articular surface (Figs. 3-A and 3-B).

DIAGNOSIS

Close cooperation between surgeon and roentgenologist is essential for determining the nature of a fracture of the calcaneus, and for separating cases suitable for conservative treatment from those in which open reduction is necessary. Lateral as well as axial roentgenograms are, of course, always essential. Anatomical variations are considerable; the tuber-joint angle varies normally between 10 and 40 degrees, and the length and width of the fractured tuber cannot be measured with accuracy. Corresponding roentgenograms of the uninjured foot are, therefore, always necessary.

The posterior facet of the talocalcaneal joint, where the essential fracture is located, is, however, not easily demonstrable in roentgenograms. The joint surfaces are convex and slope laterally. A lateral roentgenogram, therefore, shows the inner part of the posterior facet, together with the medial and anterior facets, but completely fails to demonstrate the remainder of the joint. The sinus tarsi, however, is always visible, and the lateral portion of the posterior facet always extends forward to this landmark. An oblique lateral roentgenogram, taken from below and posteriorly, provides a clear projection of this portion of the joint as it reaches the posterior end of the sinus tarsi. In this roentgenogram a compressed fragment is visible, despite the background of the medial fragment, and is recognizable as a rather faint shadow. This is easily overlooked; it will probably go unnoticed unless the attention of the roentgenologist is directed particularly to it. In the axial roentgenogram, however, the compressed fragment appears more or less clearly. In any event, the ledge which interrupts the outline of the articular facet should always be visible (Fig. 4).

If the lateral block is large and its articular surface is deeply depressed, the talus

FIG. 4

FIG 5

Fig. 4: Axial view of the shearing fracture, showing compression in the lateral block. The ledge at the articular surface is visible

Fig. 5: The compression cavity is visible after reduction of a depressed articular fragment by means of an elevator.

may rotate on its longitudinal axis to produce a lateral widening and subluxation of the ankle joint.

The surgeon should obtain the opinion of the roentgenologist on the following points: (1) whether a simple linear fracture or a combined linear and compression fracture is present; and (2) if comminution and compression are present, the size of the depressed fragment of the articular surface and the height of the ledge between the two parts of the articular facet should be determined.

TREATMENT

Double transfixion and traction, according to the method of Böhler, have apparently been accepted widely as the standard technique for the treatment of these fractures. The method is recommended without reservation, not only by German writers, but also by British and American authors, including Watson-Jones, Schofield, and Jackle and Clark. Recently, however, Böhler himself fails to show enthusiasm for this method. In the sixth edition of his textbook, he recommends in certain cases reduction with the aid of the Phelps-Gocht clamp, a rather complex instrument which secures a three-point grip on the foot. The reduction is then stabilized by the introduction of a pin from the back of the heel, according to the technique of Westhues.

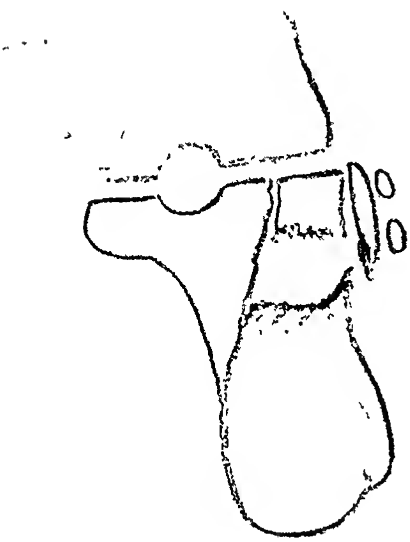

Fig. 6

Diagram showing the defect under the reduced fragment of the articular surface; this is formed by the compression of spongy bone.

In 1932, Lenormant and Wilmoth described a method of open reduction similar to that used by the author. They explained the depression of the articular surface as being the result of fracture of weak subjacent cancellous bone, containing relatively few trabeculae. Other surgeons have attempted open reduction and osteosynthesis by means of metal pins. Open reduction, however, has never been adopted widely, the apparent reason being that it has offered little advantage, owing to the difficulty of maintaining a stable reduction.

In order to shorten the period of total disability in cases of fresh comminuted fracture, the author decided at first to try primary arthrodesis of the talocalcaneal joint. This operation, carried out on three patients, was not wholly satisfactory. The exposure was necessarily extensive and impaired the nutrition of the fragments. The osseous substance, which had already been compressed laterally by the fracturing force, was further reduced by removal of the articular surfaces; it was, therefore, difficult to avoid excessive valgus deformity. The result in each case was a fused subtalar joint with a valgus deformity of the foot. The functional results were moderately good.

These operations demonstrated that, contrary to previous conceptions, the depressed fragment bearing the articular surface was sharply outlined, firm, and stable. By means of an elevator, introduced into the compressed substance beneath it, this fragment could be levered upward and forward to restore the normal structure of the joint (Fig. 5). If, however, the entire lateral block was reduced by traction on a wire transfixing the tuber, the impacted articular fragment could be seen to move downward and backward, heightening the intra-articular ledge and thereby increasing the displacement within the joint. This demonstrated clearly that commonly used methods of reduction actually have an unfavorable effect on the essential factor of the articular injury. It was evident, also, that the normal structure of the joint and the normal contour of the calcaneus could be restored by open reduction with a moderate amount of surgical exposure.

An operation of this type has now been carried out in twenty-three cases. Being based directly on the details of the injury, it is divisible logically into three steps: (1) reduction

Fig. 7-A

Fig. 7-B

Fig. 7-C

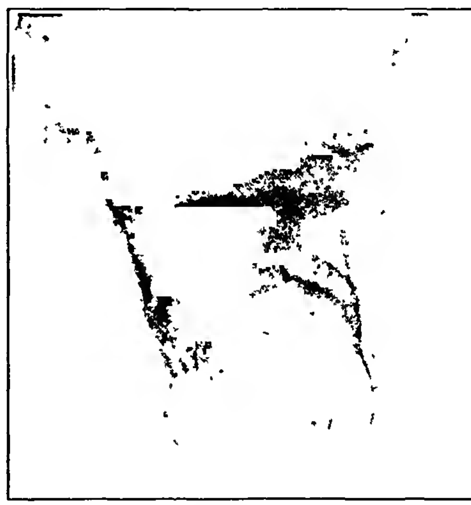

Fig. 7-D

Fig. 7-A: Comminuted fracture, Type II, before reduction.
Fig. 7-B: After open reduction and filling.
Figs. 7-C and 7-D: Lateral and axial views, one year after operation.

of the entire lateral block of the shearing fracture; (2) reduction of the secondary compression fracture, involving the articular surface; and (3) filling the bony defect, which results from elevation of the articular fragment to its normal position.

A curved incision, six centimeters in length, is made beneath the lateral malleolus. The sheath of the peroneal tendons is incised, and the tendons are displaced forward. At the proximal portion of the peroneal sheath, the incision is deepened to divide the middle part of the fibulocalcaneal ligament and expose the talocalcaneal joint. If the foot is carefully dislocated into a varus position over a wedge, it is possible to look into the joint and to observe and measure the pathological ledge between its facets.

A transfixion wire is drilled into the angle between the point of the tuber calcanei and the Achilles tendon, and is tightened into a bow. Traction downward and backward will now reduce the lateral block of the shearing fracture without difficulty. An elevator is introduced into the compressed substance under the articular surface, and is used to lever this fragment into position until the intra-articular ledge is level. The reduction, however, is extremely unstable. If the traction and the elevator are released, displacement recurs.

When the fragments are held in the position of reduction, a large defect formed by the compression of spongy bone appears beneath the articular fragment (Fig. 6). The presence of this defect explains a frequent end result of the conservative treatment of

fractures of the calcaneus. After temporary reduction (probably the articular fragment is never perfectly repositioned), the bone collapses to produce traumatic flat-foot in the valgus position.

The compression cavity, which is usually about the size of the end of one's thumb, is next measured. A transplant, taken from the crest of the ilium, is shaped to correspond to the cavity; it should be slightly larger than the defect in the calcaneus. This graft is hammered into the cavity by means of a tamp.

The reduction will now be quite stable. The fragment of the articular surface is pressed firmly upward against the articular surface of the talus; the lateral block shows no tendency toward dislocation. The transplant serves as a key for locking the reduction. Postoperative roentgenograms show that the normal contour of the calcaneus has been restored (Figs. 2-A, 2-B, 3-A, 3-B, 7-A, 7-B, 7-C, and 7-D).

For postoperative immobilization, a short leg cast is used; transfixing pins are unnecessary. Two to four days after operation, the patient is allowed to walk on crutches without bearing weight on the injured foot. After twelve weeks, the plaster is replaced by a zinc-paste stocking and a strong shoe with a longitudinal arch support.

RESULTS

This operation has been carried out in twenty-three cases of fracture of the calcaneus with a depressed articular fragment. Nineteen of the patients were men and four were women. Their ages ranged from thirty to seventy-two years. In twelve cases a Type I injury was present; in eleven cases it conformed to Type II. Two of the patients had simple linear fracture of the opposite calcaneus. In one case the ankle joint was destroyed by a central compression fracture of the lower end of the tibia.

No unusual technical difficulties were encountered during these operations. In all cases the convalescent period, in striking contrast with that after treatment by transfixion and traction, offered remarkably little inconvenience. It was of great advantage that the patient was not confined to bed, but could be up a few days after operation.

Follow-up examinations of these patients, who were treated between May 1944 and March 1946, have shown remarkably favorable results. All of the patients were back at their previous work from four to eight months after the operation. The majority have shown, when examined from six months to two years after operation, painless pronation-supination in the subtalar joint of from 15 to 30 degrees (one-quarter to one-half the normal range). In one case, which must be regarded as a failure, a painless mobility of only 5 degrees is present; one presents painless ankylosis in good functional position. In all cases the shape of the longitudinal arch is the same as that of the uninjured foot. Most surprising and encouraging is the fact that the mobility is really painless; in this respect, these cases form a sharp contrast to those treated by conservative methods.

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SLIPPED EPIPHYSIS IN THE ADOLESCENT HIP

A Reconsideration of Open Reduction*

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A review of the literature on slipping of the upper femoral epiphysis impresses one with the unsatisfactory results of treatment, especially of the severely displaced epiphysis which requires reduction. Almost uniformly, reports show good results in the cases with a minimal degree of slipping, but a depressing percentage of poor results in those with severe or complete slipping. Therefore, it seems important to report any refinement of method which gives promise of improving the prognosis in this discouraging condition.

If the problem of treatment were only that of correcting deformity, the simple measure of intertrochanteric osteotomy after union of the epiphysis would suffice. This procedure might still be useful in the occasional case in which the displacement of the neck is mostly *anterior (anteversion), and traumatic arthritis from impingement of the* neck against the acetabulum has, therefore, not supervened. In most cases, however, this fortunate condition does not obtain, and the desirability of early reduction of the epiphysis is made obvious.

In most cases, so-called traumatic arthritis is the late secondary result of ischaemic necrosis of the capital epiphysis. This complication is to be feared more than deformity alone, and is the cause of most of the poor results in any reduction treatment, open or closed. However, gross aseptic necrosis seldom occurs in untreated cases. Therefore, the treatment must cause the necrosis by further injuring the blood supply of the epiphysis. In too many instances, treatment thus defeats itself. Many excellent reductions of a displaced epiphysis are followed by necrotic changes, which always end in limitation and, later, in osteo-arthritis and even ankylosis. Preservation of the blood supply of the epiphysis is the crux of the problem of treatment.

The blood supply to the capital epiphysis of the femur can come from only three sources:

1. A few small vessels which penetrate the cartilage plate from the neck.
2. The vessels in the ligamentum teres.
3. The vessels in the periosteum of the neck, which in childhood is much thicker and more vascular than in the adult.

The vessels penetrating the cartilage are, of course, destroyed when the epiphysis slips. The vessels in the ligamentum teres are small and may be absent. The periosteal vessels are also torn, at least on the anterior aspect of the neck, as the head slips posteriorly. Thus, at best, the blood supply of the epiphysis is meager after slipping occurs. However, avascular necrosis is practically never encountered in untreated cases, although occasionally we see degenerative changes in the articular cartilage which may be secondary to deficient circulation in the underlying bone. In such cases, the roentgenogram shows narrowing of the joint space, but no change in the density or contour of the head of the femur. When this narrowing of the joint is present, no treatment will give good results; and, in fact, ankylosis may occur with or without treatment. It is the author's belief that often the treatment has been blamed for poor results which are actually due to this pre-existing degenerative condition (Figs. 1-A and 1-B).

During the last seven years, the author has observed and treated by various methods, twenty-six patients with slipping of the capital epiphysis (thirty-three hips). These experiences have led to certain conclusions concerning the probable cause of many of

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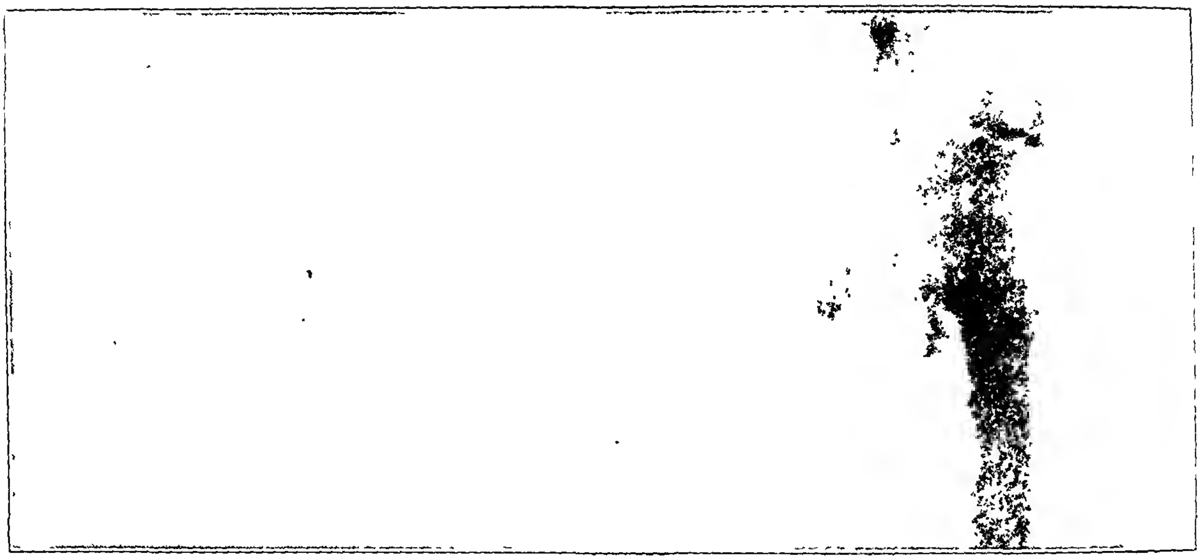

Fig. 1-A

H. S. Roentgenogram shows narrowing of joint space without gross necrotic changes in the epiphysis. The significance of this was not appreciated at the time of treatment. Compare with normal right hip.

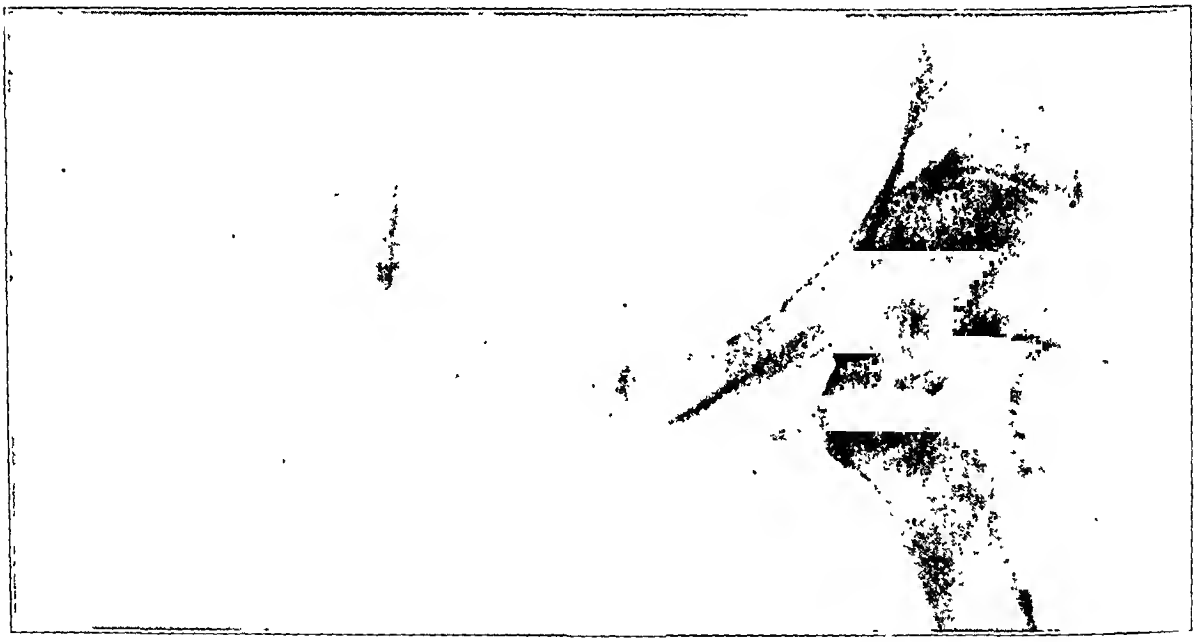

Fig. 1-B

Ankylosis occurred within six months after intertrochanteric osteotomy. The condition ultimately progressed to solid bony ankylosis without roentgenographic evidence of necrosis. In such a case, any form of treatment will fail.

the bad results heretofore obtained, and to the development of a technique of treatment which is thought to avoid some of the pitfalls of the past, through meticulous respect for the remaining blood supply of the epiphysis.

There seems little doubt that injudicious manipulation to accomplish closed reduction, and surgical trauma in open reduction, have been the sources of most of our difficulty. Closed reduction should be condemned, except for a gentle manipulation to reduce an *acute* displacement. Manipulation should not be expected to effect reduction of an epiphysis which has slipped gradually or one which has been displaced for several weeks or months; for the epiphysis is firmly adherent to the neck by fibrous tissue and sometimes by callus, while it is anchored to the acetabulum by only the ligamentum teres. Usually manipulation of such a hip not only fails to accomplish its purpose, but it damages the ligamentum teres. Loss of this source of blood supply may alone lead to aseptic necrosis

in certain cases, and in any case it makes later open reduction more hazardous and uncertain. Even if the manipulation is successful, the remaining periosteal attachments of the epiphysis must be torn to allow the reduction. Then necrosis will surely occur, unless by chance there remains sufficient circulation through the ligament.

In those cases requiring open reduction, great care should be taken to preserve both the ligamentum teres and the periosteum on the posterior and inferior surfaces of the neck. The epiphysis should not be entirely detached from the neck in this region. If both the ligamentum teres and the postero-inferior portion of the periosteum are uninjured, the blood supply should be practically the same as before operation, and the head should survive.

It is generally and logically accepted that, if the displacement of the epiphysis is more than one centimeter, either downward or posteriorly, reduction is necessary. For practical purposes these severe displacements should be divided into two groups: (1) the acute traumatic cases, and (2) the cases with gradual slipping.

There undoubtedly are some purely traumatic separations of the capital femoral epiphysis. These generally are in older patients who sustain severe wrenching injuries of the hip. These displacements are always acute, usually complete, and probably should be considered as fractures, like traumatic epiphyseal separations in other bones. In these cases, if symptoms have been present for less than two weeks, manipulatory reduetion may be tried. Often reduction can be accomplished by gentle traction and internal rotation, followed by or combined with abduction. These acute cases should be the *only exceptions* to the rule against manipulation. The reduction must be easy, or attempts should be abandoned. Vigorous manipulation, as by the Leadbetter manoeuvre, or strong traction on the orthopaedic table should not be used. If the epiphysis can be reduced easily, it should immediately be fixed by a Smith-Petersen nail. Excellent results will be obtained in this type of case if only the hips in the *acute* phase are manipulated (Figs. 2-A and 2-B).

If the slipping has been more gradual, or in the acute cases of more than two weeks' duration, open reduction should be done *without any preliminary trial of manipulation.* It is striking that in most reported series, if the acute cases are excluded, the pereentage of poor results is about the same from either closed or open reduction. This may indicate that much the same damage is done by both forms of treatment. It is the author's opinion that both methods often fail because of further damage to the blood supply of the epiphysis, chiefly the postero-inferior periosteum. Of course, the present statistical picture is

Fig. 2-A

Fig. 2-B

Fig. 2-A: O. K. In this case of acute traumatic slipping, reduction was achieved by manipulation and the epiphysis was nailed by "blind" technique two days after slipping.
Fig. 2-B: Shows result twenty-seven months later. Function was normal.

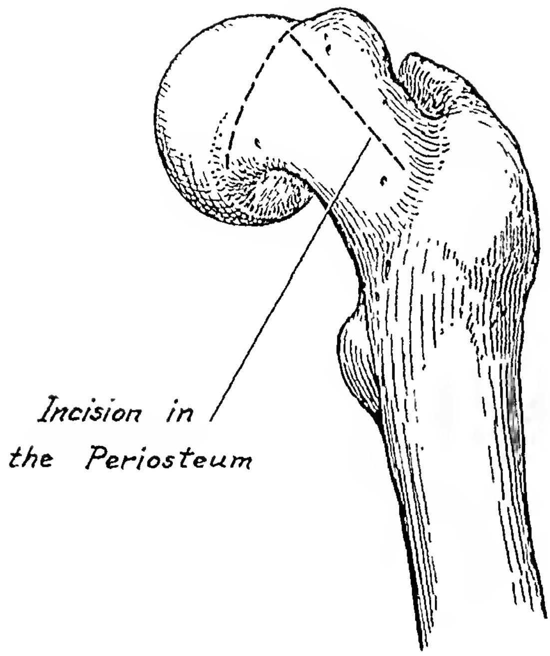

FIG. 3-A

The whole lower extremity is prepared and draped to permit free manipulation. The orthopaedic table is not used. The hip is exposed by the Smith-Petersen incision, and the capsule is divided by a T-shaped or L-shaped incision, close to the rim of the acetabulum.

Fig. 3-A: Shows the T-shaped incision in the periosteum. The transverse portion is immediately distal to the rim of the epiphysis; the longitudinal limb should be slightly above the mid-line of the neck.

Fig. 3-B: The periosteum is carefully elevated, without tearing. It is not necessary at this stage to elevate completely around the neck. The bone should be removed piecemeal rather than by through-and-through osteotomy, with danger to the posterior portion of the periosteum. The last of the bone and callus should be carefully removed, to preserve the posterior and inferior portions of the periosteum.

Fig. 3-C: After the neck has been entirely freed from the head and the periosteum, and has been sufficiently shortened to allow easy reduction into the head, a guide wire for a Smith-Petersen nail is introduced through a lateral incision and drilled blindly through the neck until the point barely emerges in its center.

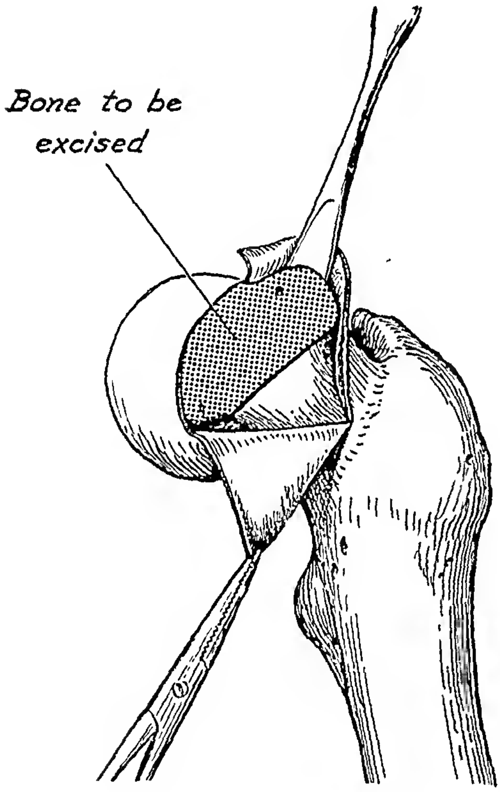

FIG. 3-B

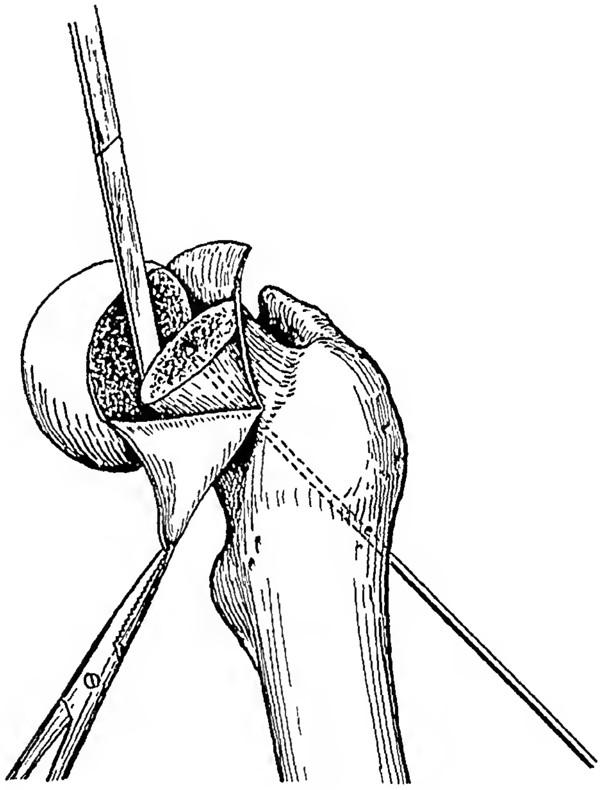

FIG. 3-C

confused, because heretofore most patients operated upon have first had unsuccessful manipulation. Therefore, it is impossible to determine how many of the poor results have been caused by the operation alone. Any study of operative results in which manipulation has also been tried must be very inaccurate indeed. However, it is to be hoped that within a few years a large series of cases can be accumulated in which no preliminary manipulation has been done; and in which, at operation, the periosteum on the posterior and inferior aspects of the neck has been carefully preserved both from actual tearing and from tension. The method we are advocating does this, and so far it has given very gratifying results.

This is not a new operation, but only a refinement in technique, based on the principles just indicated. It is very similar to the open reduction described by Wilson in 1924, but for one important particular: Except possibly in the acute cases of less than two

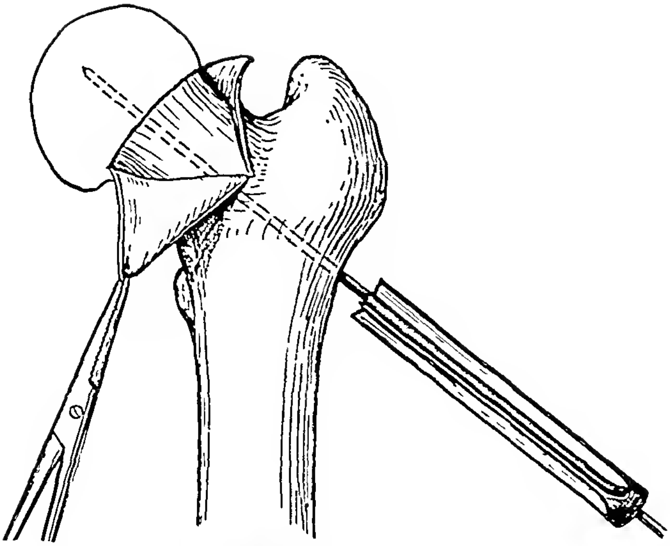

FIG. 3-D

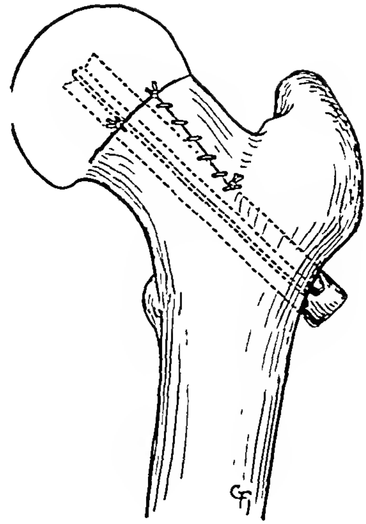

FIG. 3-E

FIG. 4-A

FIG. 4-B

Fig. 3-D: The neck is then reduced into the head, a thin skid being used to steady the head, but not to pry. The guide wire is then drilled in 1.5 centimeters farther. By subtracting the protruding portion of the wire from the length of a similar wire, a nail of appropriate length may be selected.

Fig. 3-E: The Smith-Petersen nail is driven by many light blows of the mallet, rather than by fewer heavy blows. The neck must be firmly impacted against the head. The periosteum is closed by a running catgut suture, and tacked to the edge of the epiphysis by several interrupted sutures. Thus the neck is again completely covered with synovial membrane. The incision in the capsule is closed carefully.

Fig. 4-A: J. C. B. Complete slipping with callous union.

Fig. 4-B: Result nine months after open reduction, just before the nail was removed. Function was practically normal.

Fig. 5-A: J. K. Patient had complete slipping, with fibrous union; symptoms of about three months' duration.

FIG. 5-A

weeks' duration, no attempt should be made to prize the head up onto the neck; but sufficient bone should be removed on the anterior and superior aspects of the neck to allow the neck to be easily reduced into the head. This amounts to a cuneiform osteotomy, even in recent cases. We believe that this step avoids tearing or even excessive tension on the posterior and inferior periosteal vessels, as would happen if a posteriorly displaced epiphysis were prized forward onto an unshortened neck; this is especially true if several weeks have elapsed, allowing time for the periosteum to shorten and even for callus to form in the posterior angle between the neck and the epiphysis.

Gentleness is just as important in open manipulation of the epiphysis as it is in closed reduction. The periosteum should be incised and carefully elevated from the neck, and the osteotomy and reduction should be carried out strictly within the periosteal tube. The periosteum in these cases strips up easily, and this technique is perfectly feasible. After the epiphysis has been realigned, it is fixed by a Smith-Petersen nail, introduced over a guide wire through a smaller lateral incision. The periosteum is carefully sutured and attached to the edge of the epiphysis, completely covering the neck again with synovial membrane (Figs. 3-A, 3-B, 3-C, 3-D, and 3-E).

FIG. 5-B
Roentgenograms taken seven months after open reduction.

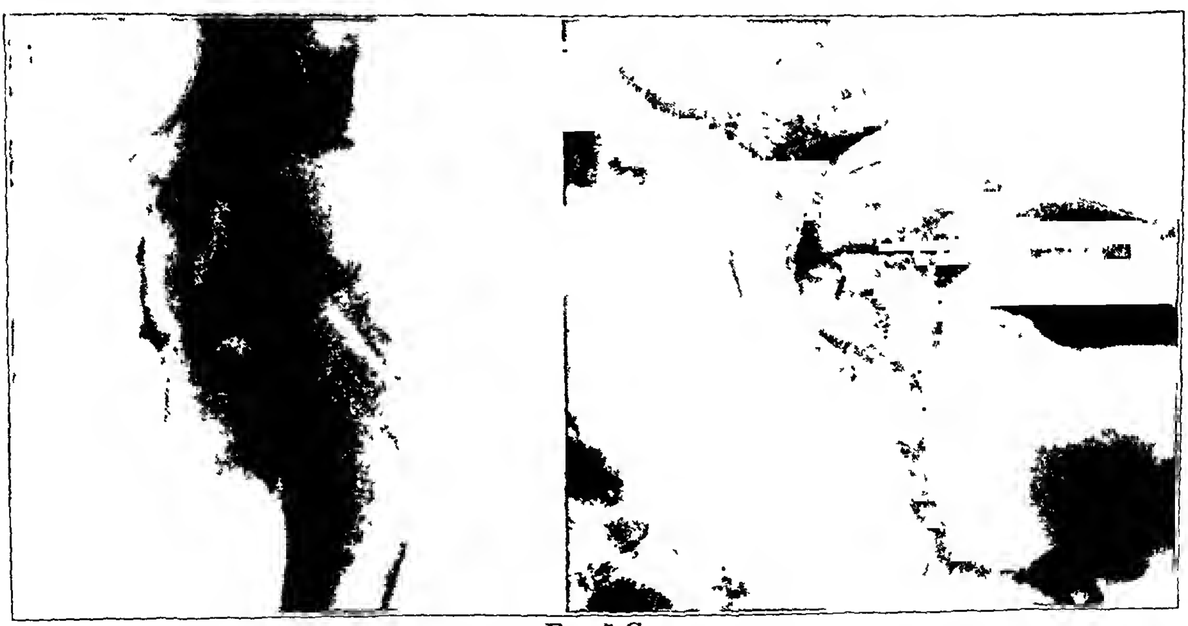

FIG. 5-C
Twenty-eight months after open reduction, and about one week after removal of nail.

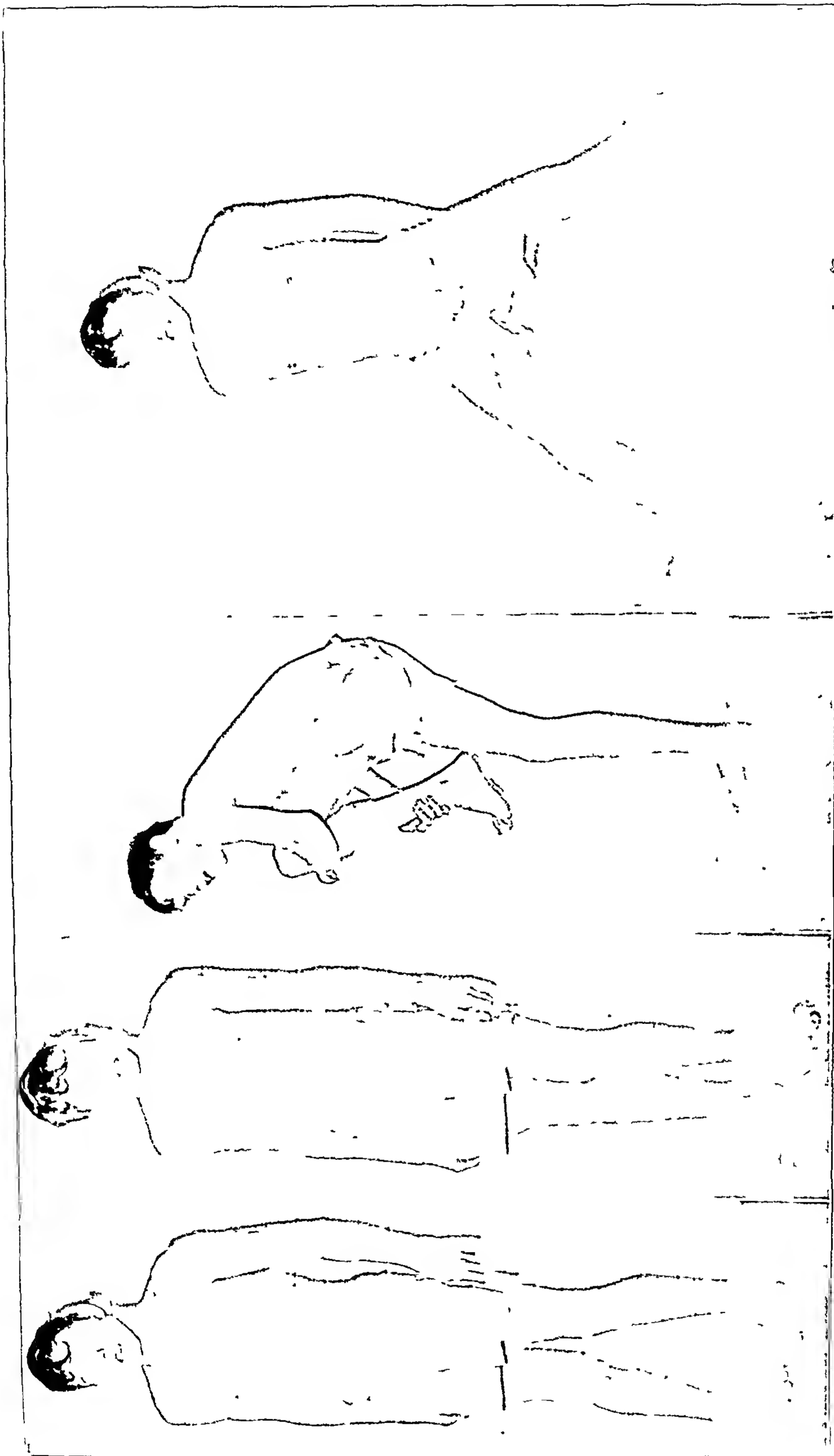

FIG. 5-D FIG. 5-E FIG. 5-F FIG. 5-G

Showing range of motion of left hip, twenty-eight months after open reduction. Function is practically normal, but patient has shortening of one inch

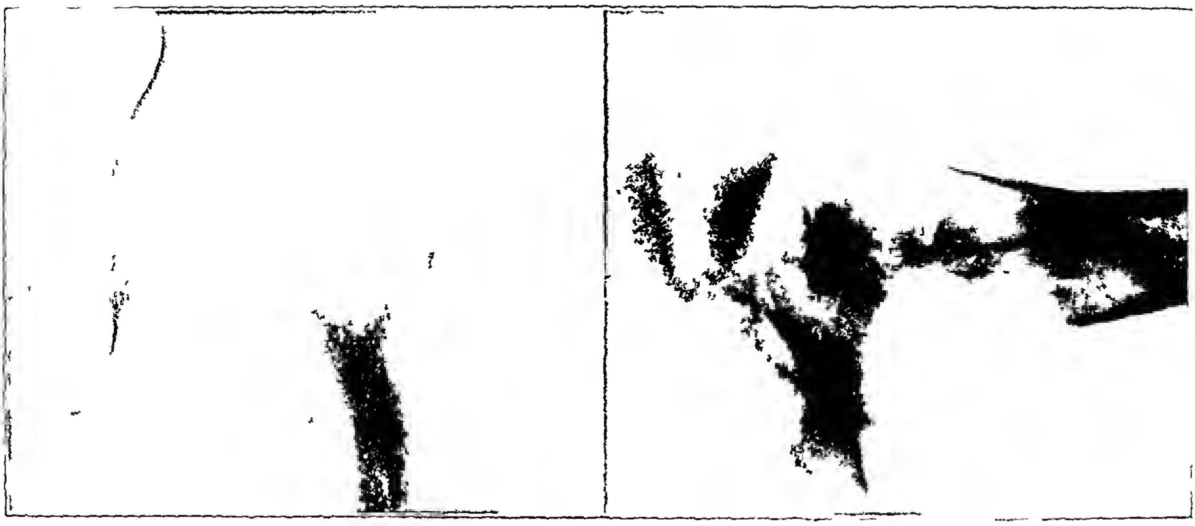

Fig. 6-A

G. R. This patient had complete slipping, with union by bony callus. Symptoms had been present for about six months.

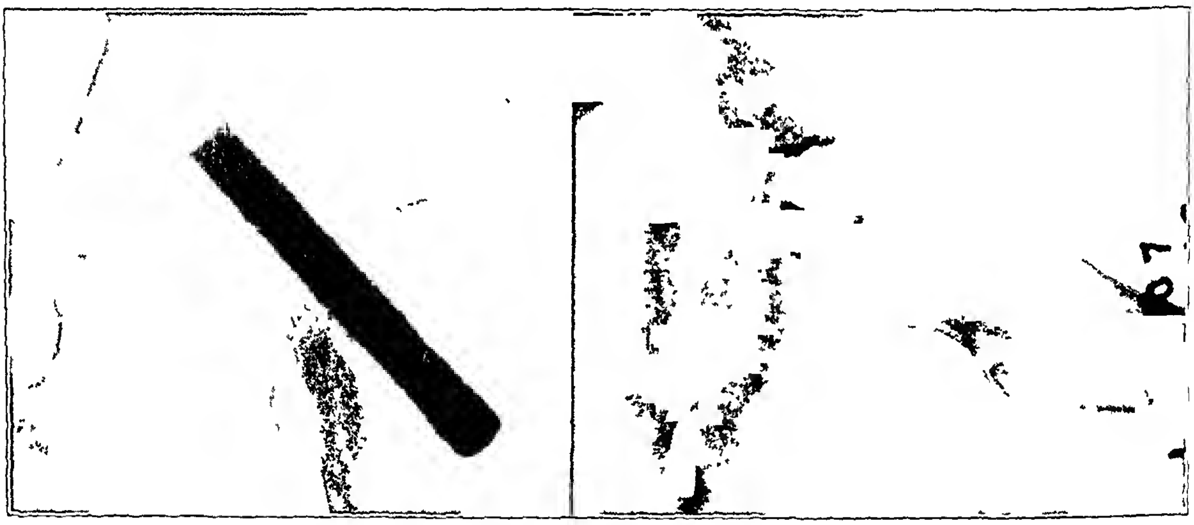

Fig. 6-B

Roentgenograms taken six months after open reduction.

Fig. 6-C

Showing hip fourteen months after operation, just after nail had been removed.

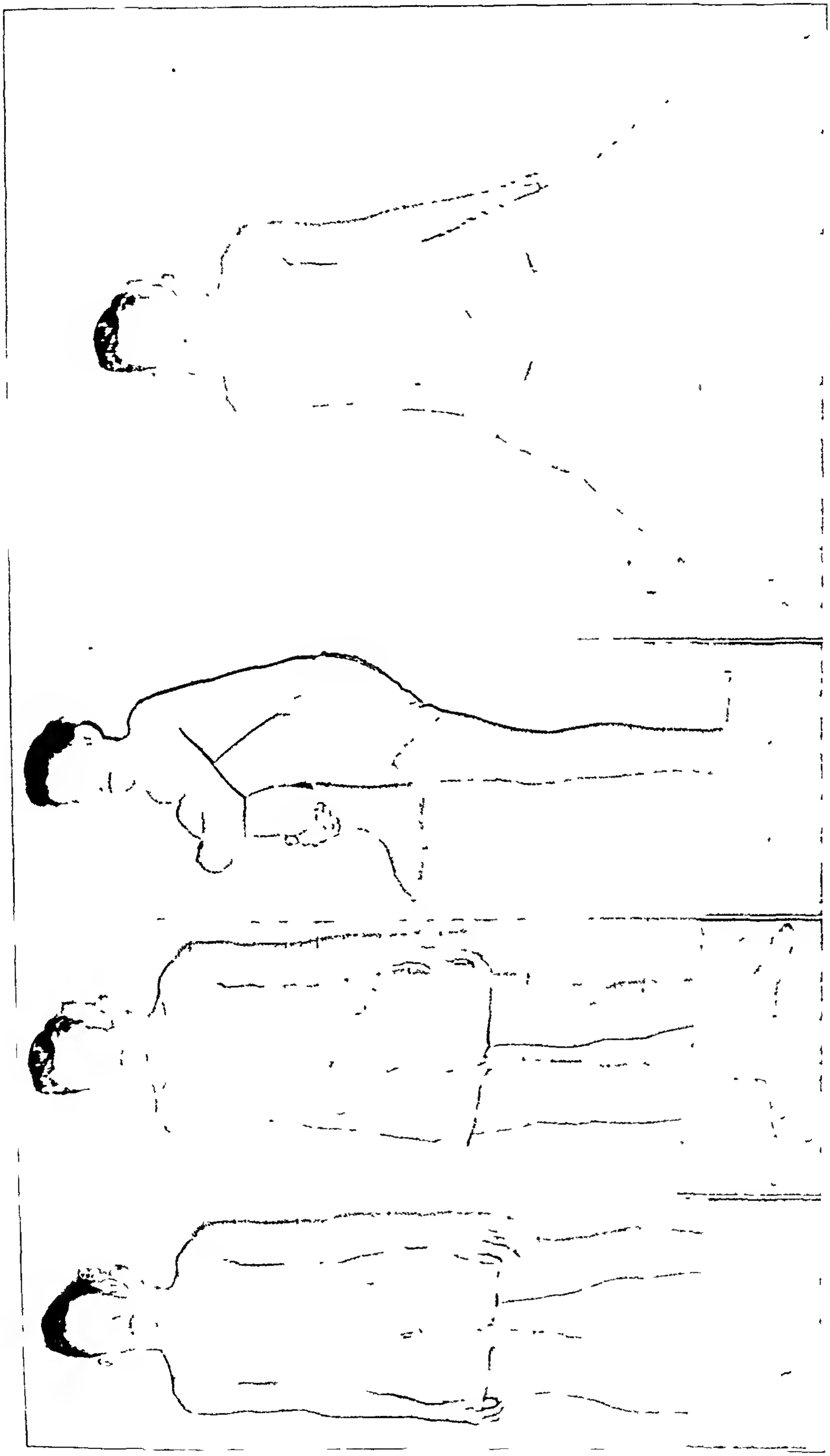

Fig. 6-D Fig. 6-E Fig. 6-F Fig. 6-G

Showing motion of left hip, fourteen months after open reduction. Function was excellent; shortening of one-half inch was present.

This method is equally applicable when the epiphysis is united by bone in a completely displaced position, although in these older cases somewhat more bone from the neck should be sacrificed, so as to avoid excessive tension on the periosteum when the reduction has been made. A seemingly radical sacrifice of bone will not shorten the limb more than an additional quarter of an inch.

The author has used this method in eight cases since 1943. One case is too recent to be included in this series. The time since operation averages twenty-one months in the other seven, with the oldest thirty-nine months, and the most recent ten months. Some may say that the whole series is too recent to be used in determining final results. This may be true in regard to possible future arthritic changes, but I believe that we are past the danger of aseptic necrosis, which is the cause of most of the poor early results and is also the chief factor in the development of serious late osteo-arthritis. Six of these seven patients should be classified as having excellent results, with almost normal function as regards limp, pain, and motion. In one of them, however, trouble may develop later, although it has been thirty-nine months since her operation. Four months after operation, necrosis of the upper anterior quadrant of the head developed, possibly because the nail may have cut the blood supply to this area. There is now some incongruity of the head and, despite excellent present function, osteo-arthritic changes may develop many years hence. In only one case has a poor result followed the open reduction. In this one, the nail was too long and worked through the head, gouging a defect in the acetabulum before the situation was discovered and the nail was removed. This girl, twenty-one months after operation, has marked limitation and a bad limp from an adduction deformity of the hip. Arthroplasty will undoubtedly be required. This poor result, however, should be attributed to faulty technique rather than to the method.

In 1944, Green described an almost identical technique, and reported two cases, treated in a similar manner with excellent results. If our seven cases are added to these two, we would have eight excellent functional results in nine cases so treated. The only poor result was due to a technical error, and not to necrosis. In only one of these cases (our first) has any degree of necrosis occurred. As just mentioned, there is in this case excellent present function, but the probability of later arthritic changes. Complete displacement was present in all of these cases, and three of the author's cases had bony union (Figs. 4-A, 4-B, 5-A through 5-G, and 6-A through 6-G).

This operation is difficult and should not be undertaken lightly. The technique is exacting and tedious, and will test the ability of the most capable orthopaedic surgeon. Nonetheless we believe it to be worth while in this group of cases, always so discouraging when treated by other methods.

CONCLUSIONS

1. Most poor results are caused by improper treatment, and are due chiefly to avascular necrosis in the epiphysis.
2. Necrosis in the epiphysis is caused by further damage to its blood supply through the ligamentum teres and the periosteum on the posterior and inferior aspects of the neck.
3. Manipulation should be condemned except in acute traumatic cases, and it should be gentle. If reduction is not easy, closed methods should be abandoned.
4. Patients in the so-called preslipping stage and those with minimal slipping (less than one centimeter) are best treated by nailing *in situ* without reduction.
5. When displacement is more than one centimeter, and is gradual or has existed longer than two weeks, open reduction should be done without preliminary manipulation. This must be accomplished with due respect for the blood supply of the epiphysis.
6. In old united cases, if there is a good hip joint, intertrochanteric osteotomy may be beneficial. Later in life, arthroplasty offers much improvement for the old arthritic hips and especially for the cases with ankylosis.

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OPERATIVE THERAPY FOR SLIPPED UPPER FEMORAL EPIPHYSIS

AN END-RESULT STUDY *

BY CARL E. BADGLEY, M.D., A. S. ISAACSON, M.D., J. C. WOLGAMOT, M.D., AND J. W. MILLER, M.D., ANN ARBOR, MICHIGAN

The treatment of displacement of the upper femoral epiphysis has generally been regarded with dissatisfaction and uncertainty. During the past twenty years the conservative therapy, consisting of manipulative reduction or reduction by traction and external fixation, has been superseded by internal fixation, frequently associated with open reduction. The early optimistic reports of the results of such operative therapy have not been substantiated in many clinics. Aseptic necrosis and stiff hips have resulted so frequently that the present trend is again toward conservative therapy. Common practice consists of a trial of skeletal traction and correction of position by abduction and internal rotation for a period of several weeks; if successful, this position is maintained until fusion occurs. If failure of correction is obvious, trochanteric osteotomy is a favorite procedure. The trochanteric osteotomy is intended primarily to correct the external-rotation deformity and to alter the position of the head so as to improve the mechanics of the joint.

For a number of years, since Wilson's operative replacement of the malunited upper femoral epiphysis, the authors have utilized the following postulates as a guide in the treatment of displacement:

1. A displacement of not more than one third of the diameter of the femoral epiphysis, as observed primarily in the lateral roentgenographic view of the hip joint, has been accepted as a satisfactory position. These hips, and those showing displacement of less than one third the diameter or no displacement (the "preslipping" stage) have been treated by internal fixation without any attempt at correction, to prevent progression of the deformity.

2. Displacement of the upper femoral epiphysis beyond this extent, usually associated with deformity and disability, requires improvement of the position of the epiphysis in its relationship to the neck.

3. Skeletal traction has been used for the reduction of the displacement. Should a

* Read at the Annual Meeting of The American Academy of Orthopaedic Surgeons, Chicago, Illinois, January 28, 1947.

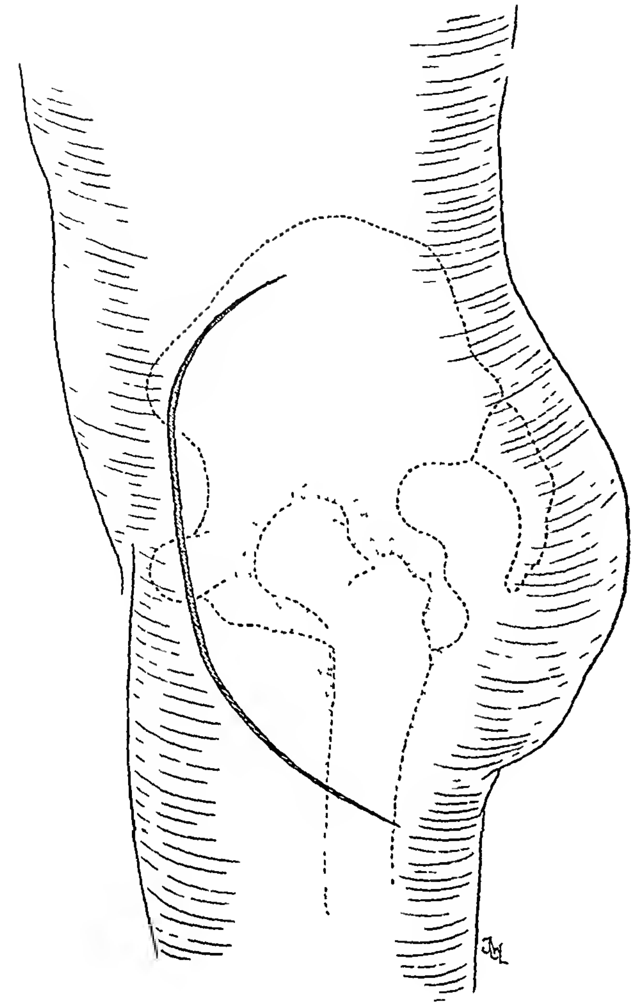

Fig. 1

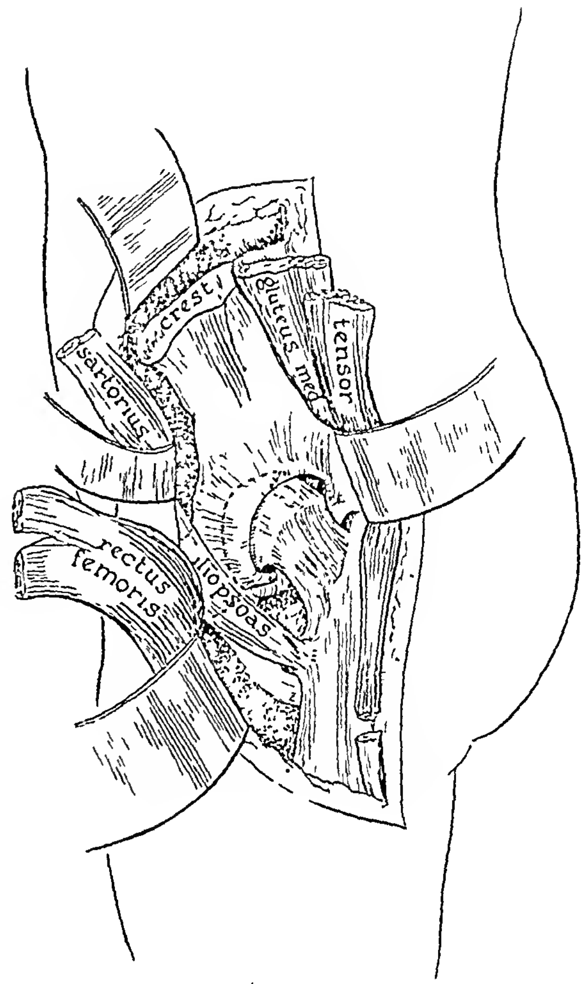

Fig. 2

satisfactory reduction result, its maintenance by internal fixation until the femoral epiphysis has become fused has been the most successful method of treatment. The acute traumatic type or the chronic type of slipping, suddenly completed by trauma, is usually corrected readily by this method; *mild* manipulation may be successful to complete the correction.

4. Unsuccessful skeletal traction necessitates open reduction of the displaced epiphysis. Not infrequently, removal of a wedge of newly formed bone anteriorly has been required to allow proper realignment. Pin or screw fixation to maintain correction until fusion occurs has been advisable.

5. The ultimate fate of the neglected and displaced upper femoral epiphysis is most certainly degenerative arthritis. Correction or prevention of the displacement has been the rule of therapy. Correction, if the epiphyseal line is still open and active, has been made intracapsularly at the site of the lesion. The subtrochanteric or intertrochanteric osteotomy has been reserved for the patient with a malunited, fused upper femoral epiphysis and a hip which has maintained fair or good motion, but has an external-rotation deformity.

This thesis is based upon the rationale of therapy, directed toward prevention of displacement of the epiphysis in the early phase by internal fixation; in the later stage of more marked displacement, therapy is directed toward correction of the deformity where it has occurred at the epiphyseal juncture with the neck, and maintenance of the correction by internal fixation. The authors have felt that correction by osteotomy in the trochanteric region did no more than produce temporary improvement, as the primary pathological condition was not corrected. The end results have been reviewed from time to time.

Although failures and disappointments have followed this program of therapy, we

have felt that the percentages of success have justified a continuance of this scheme. An end-result study is presented of the operations on seventy-eight hips, which represent various stages of epiphyseal displacement in sixty-six patients (twelve, or 18 per cent., having bilateral involvement), all of whom were treated surgically in accordance with the postulates listed. Two of these patients, without previous treatment, entered the Clinic because of extensive degenerative arthritis, producing incapacitating symptoms, for which Vitallium-cup arthroplasties were performed initially. These two cases illustrate that the arthritis is not necessarily the fault of an operative procedure, but may develop spontaneously in this peculiar lesion. Because of marked deformity and fixation of the hip, a Whitman reconstruction operation was performed in a third case, early in this series. The remaining sixty-three patients or seventy-five hips were operated upon as follows:

Open reduction was carried out on thirty-four hips for a malunited epiphysis; this required the removal of an anterior cuneiform wedge of bone. This overgrowth of bone lies between the displaced epiphysis and the neck of the femur. Fixation was obtained by means of a Smith-Petersen nail or by two screws.

Eleven hips were treated by open operation; an osteotomy at the epiphyseal site was performed for correction of the deformity, and reduction was maintained by external fixation,—namely, a plaster spica.

Four hips were treated by open operation with a simple osteotomy to correct the relationship between the epiphysis and the neck, followed by internal fixation.

Six patients were treated by closed reduction with traction, aided, if necessary, by very gentle manipulation. After satisfactory position had been obtained, blind nailing or screw fixation was employed.

Sixteen hips were fixed internally, without any attempt being made to correct a minor displacement.

Four hips were treated by means of the subtrochanteric type of Schanz osteotomy.

In view of the unsatisfactory results of open operative corrections reported to us by friends, the possibility of trauma from inadequate exposure has been suspected. The importance of an adequate exposure to the head of the femur should be stressed. The backward and downward displacement of the epiphysis makes exposure of the head by the ordinary procedures very difficult.

By the use, however, of the approach (Fig. 1) described by Smith-Petersen for the Vitallium-cup arthroplasty, in which the iliopsoas is exposed and retracted

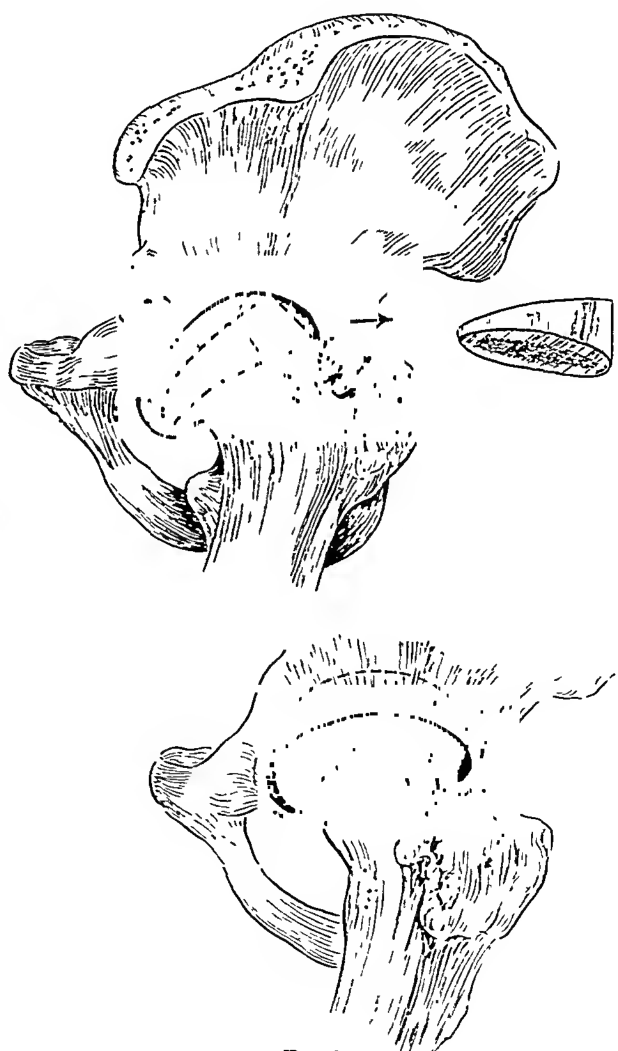

Fig. 3

medially, an excellent view of the anterior portion of the acetabulum can be obtained (Fig. 2). It is then possible to achieve a very satisfactory exposure of the head and neck of the femur, and to observe the deformity. The line for the osteotomy, if malunion has occurred, is recognized, and the plane for the osteotomy can be determined without severe retraction or levering within the joint to displace the head and neck outward. If possible, the labrum glenoidale should be preserved.

The abnormality usually demonstrated by this approach in the stage of chronic slipping is an extension of the periosteum of the neck into a fibrocartilaginous-like material, covering a new-bone formation, which fills the interval between the displaced epiphysis and the neck of the femur. The new-bone growth is most excessive anteriorly and superiorly. Union is usually sufficiently solid so that an osteotomy is necessary to free the epiphysis. Sharp demarcation of the epiphyseal line is not obvious, and, in the selection of the osteotomy site, it is essential to differentiate the true cartilage border from this fibrocartilaginous covering of the new-bone formation.

It is important not to remove the periosteum too freely from the neck. Anteriorly, however, it should be stripped, in order to find the osteotomy site. Posteriorly, it should not be stripped from its attachment to the epiphysis, so that vascularity may be maintained.

A transverse osteotomy is performed at the juncture of the true cartilage of the head with the neck. The epiphysis and neck are thus freed. Speed, of Memphis, has made an important addition to facilitate reduction and accurate reposition. With a sharp instrument inserted into the posterior portion of the freed epiphysis, the head is readily turned anteriorly and upward from its posterior position. The neck is then fitted to the epiphysis. Frequently it has been found necessary, in order to secure good approximation, to remove from the neck a wedge of bone (Fig. 3), with its base anterior and superior, to obtain proper reduction. The neck is then reduced in its relationship to the epiphysis by internal rotation and abduction of the thigh, which usually produces excellent realignment.

In former days, external fixation in a plaster spica was relied upon to maintain this correction; this method has proved unsuccessful in 50 per cent. of the cases. Internal fixation by means of the Smith-Petersen nail or screws has now been applied routinely. Although there is little difficulty in driving a Smith-Petersen nail blindly into the epiphysis in the preslipped stage, or into the epiphysis which is mildly displaced, great difficulty has been experienced in penetrating the head with the nail in those patients upon whom an open osteotomy was necessary. The head is very hard and dense. To drill and fix with the wood screws is more certain, although even here difficulty is frequently experienced in penetrating the hard epiphysis. The drill should be of the same caliber as the shank of the screw, and should penetrate to a depth equal to the length of the screw.

Postoperative care after blind nailing in the preslipped group or that with only mild displacement requires primarily the healing of the wound. Ambulation is instituted as soon as it is comfortable, but no weight-bearing is encouraged for three months.

The postoperative care in open reduction requires six weeks in the hospital. Russell traction is employed during this period, allowing early motion of the hip and knee. The patients are then ambulatory on crutches, with no weight-bearing on the hip which has been operated upon for a minimum period of three months. They are observed at three-month intervals for at least a year.

The criteria for judging the end results of these operative procedures are primarily the objective clinical findings as regards the function of the hip and the roentgenographic changes in the hip joint. The clinical end results are classified as excellent, good, fair, and poor. The goal to be attained for this condition is a normal hip, ascertained by the range of motion and function in the hip joint following the operative procedure. In this study the *excellent* hips are those in which the range of motion is essentially normal, except for a possible limitation in flexion or internal rotation, or both, of 5 to 10 degrees. Those classi-

TABLE I

CLINICAL RESULTS FOLLOWING THE OPERATIVE PROCEDURES

Operative Procedure	Results								
	Excellent		Good		Fair		Poor		Total
Wedge osteotomy and internal fixation	19	(56%)	3	(9%)	1	(3%)	11	(32%)	34
Open reduction without internal fixation	4	(36%)	2	(18%)	0		5	(46%)	11
Open reduction without wedge and with internal fixation	2	(50%)	1	(25%)	0		1	(25%)	4
Closed reduction with internal fixation	5	(83%)	0		0		1	(17%)	6
Internal fixation without attempted reduction	11	(69%)	1	(6%)	0		4	(25%)	16
Subtrochanteric osteotomy	2	(50%)	1	(25%)	0		1	(25%)	4
Totals	43	(57%)	8	(11%)	1	(1%)	23	(31%)	75

fied as *good* have flexion up to 90 degrees with no flexion contracture, and internal rotation beyond 10 degrees without pain. Those classified as *fair* have the same limitation of motion and mild restriction as the good hips, but have a minimum amount of pain or fatigue with activity. The *poor* end results are those in which there is limitation of motion of less than 90 degrees in flexion, a flexion contracture, and a "gluteal" gait; pain may or may not be present.

This lesion usually occurs between the ages of nine and seventeen years, with an average of thirteen years and five months. In this series, one patient had symptoms of two years' duration. Forty-eight of the patients (73 per cent.) were males, and eighteen (27 per cent.) were females. The obese appearance of these patients was noteworthy. Forty-six (70 per cent.) were obese, and only 20 (30 per cent.) had normal body weight.

The duration of symptoms in all cases of displacement of the upper femoral epiphysis was slightly over six months. In those cases in which the disability was caused by trauma, the duration ranged from four days to twenty-four months; in the cases of chronic slipping of the epiphysis, the range was from one and one-half months to eighteen months. An educational campaign for early recognition and treatment of this lesion is certainly indicated, and would be particularly valuable in this lesion with its limited age incidence, appearance of obesity, and characteristic clinical signs.

The duration of follow-up study in the cases reported here ranged from two months to twelve years, with an average of thirty-four months. In five cases in which the hip was operated upon, the period of follow-up was less than six months. Two of these patients are still under medical observation. The period of study of these cases extended from 1934 until December 1946. In response to a recent request, a number of these patients returned to the Clinic for check-up studies. Most of these had maintained the functional results observed a few months after operation.

The clinical results of the various operative procedures are shown in Table I.

Of the seventy-five hips * operated upon by all surgical procedures. forty-three (57 per cent.) had excellent clinical results; eight (11 per cent.) had good clinical results; one (1 per cent.) had a fair result; and twenty-three (31 per cent.) had poor results.

Of thirty-four patients in whom a wedge osteotomy with internal fixation was performed, nineteen (56 per cent.) had excellent clinical results; three (9 per cent.) had good clinical results; one (3 per cent.) had a fair result; and eleven (32 per cent.) had poor results.

* One hip of this series has been excluded, as our original operation was a Whitman reconstruction.

The results in eleven patients, in whom an open replacement of the head was performed without the use of internal fixation, showed that four (36 per cent.) had excellent clinical results; two (18 per cent.) had good clinical results; and five (46 per cent.) had poor results.

The open reduction without wedge and with internal fixation, carried out in four cases, resulted in two excellent results (50 per cent.), one good result (25 per cent.), and one poor result (25 per cent.).

In six patients in whom a closed reduction was obtained by means of traction or gentle manipulation and maintained by internal fixation, five (83 per cent.) had excellent clinical results and one (17 per cent.) had a poor clinical result.

Of sixteen patients in whom no attempt was made to correct minimum displacement, and internal fixation was used to prevent further deformity, eleven (69 per cent.) had excellent clinical results, one (6 per cent.) had a good clinical result, and four (25 per cent.) had poor clinical results.

Of four patients upon whom subtrochanteric osteotomy was performed, two had excellent clinical results and one had a poor clinical result. The poor result was undoubtedly due to the selection of an improper procedure. This patient had had marked limitation of motion in the hip joint before the operation had been performed.

The end results in thirty-eight hips treated by open reduction with internal fixation were as follows:

Excellent..	21 (55 per cent.)
Good..	4 (11 per cent.)
Fair..	1 (3 per cent.)
Poor..	12 (31 per cent.)

One of the patients with an excellent result has roentgenographic changes indicative of early aseptic necrosis. One patient with a good result has roentgenographic changes compatible with traumatic arthritis. In one of the patients with a poor result, non-union occurred at the osteotomy site. In the other eleven cases, the poor results were due to traumatic arthritis.

The successful results in 66 per cent. of the cases in this group would justify the procedure, if the delayed malum coxae senilis or degenerative arthritis were prevented from occurring later in life. The appearance of the hips seen ten or twelve years after

TABLE II

COMPARATIVE RANGES OF MOTION BEFORE AND AFTER OPERATION

Operative Procedures	Persistent *Normal* Range of Motion	Persistent *Equal* Limited Motion	Postoperative Motion		Total Cases
			Increased	Decreased	
Wedge osteotomy and internal fixation	1 (3%)	1 (3%)	23 (68%)	9 (26%)	34
Open reduction without internal fixation		1 (9%)	8 (73%)	2 (18%)	11
Open reduction without wedge and with internal fixation			4 (100%)		4
Closed reduction with internal fixation			5 (83%)	1 (17%)	6
Internal fixation without attempted reduction	7 (44%)	1 (6%)	4 (25%)	4 (25%)	16
Subtrochanteric osteotomy		2 (50%)	1 (25%)	1 (25%)	4
Totals	8 (11%)	5 (7%)	45 (60%)	17 (22%)	75

TABLE III

COMPLICATIONS REVEALED BY ROENTGENOGRAPHIC CHANGES CORRELATED WITH THE VARIOUS OPERATIVE PROCEDURES

Operation	Total No. of Hips Operated Upon	Complications			
		Degenerative Arthritis	Aseptic Necrosis	Non-Union of Epiphysis	Crushing of Neck
Wedge osteotomy with internal fixation	34	10 (29%)	1 (3%)	1 (3%)	0
Open reduction without internal fixation	11	3 (27%)	1 (9%)	0	1 (9%)
Open reduction without wedge and with internal fixation	4	2 (50%)	0	0	0
Closed reduction with internal fixation	6	0	1 (17%)	0	0
Internal fixation without attempted reduction	16	2 (13%)	0	0	0
Subtrochanteric osteotomy	4	1 (25%)	0	0	0
Whitman reconstruction	1*				
No operation	2	2**			
Totals	78 (100%)	18 (23%)	3 (4%)	1 (1%)	1 (1%)

* This patient had fibrous ankylosis of the hip.
** These patients had received no previous therapy, and are not included in the total of cases of degenerative arthritis as a complication.

operation makes us hopeful that a normal hip has resulted in these successful cases. Sufficient time has not elapsed, however, to be certain.

In the earlier cases, prior to the use of internal fixation, open reduction was performed on eleven hips (Table I). In the group with poor results, one head was displaced in plaster and an arthrodesis was performed subsequently; and one head and neck were crushed by a manipulation, prior to operation. External fixation without early mobility, and lack of secure fixation of the epiphysis, were responsible for the lower percentage of good results, in contrast to those obtained by open reduction with internal fixation.

Closed internal fixation without attempted correction of the deformity was carried out on sixteen hips (Table I). Those with preslipping and with mild displacement (less than one-third the diameter of the neck) fall into this group. It is surprising that this group had only a slightly higher percentage of successful results,—75 per cent. instead of 66 per cent.

TABLE IV

CORRELATION OF END RESULTS WITH DURATION OF SYMPTOMS *

End Result	Duration of Symptoms					Total Cases
	Not Stated	Less than 2 Weeks	2 Weeks to 3 Months	3 Months to 6 Months	More than 6 Months	
Excellent . .	4 (9%)	3 (7%)	9 (21%)	11 (26%)	16 (37%)	43
Good	1 (13%)	0	1 (13%)	1 (13%)	5 (62%)	8
Fair					1 (100%)	1
Poor	4 (15%)	0	8 (31%)	5 (19%)	9 (35%)	26

* Two patients, first seen with arthritic hips, had had no previous surgery.

in the thirty-eight cases treated by open reduction and internal fixation. Traumatic arthritis developed in two of the patients with poor results.

Excellent results were obtained with reduction by manipulation or traction, or both, and closed internal fixation, in five of six cases with acute traumatic displacement, in contrast to the chronic type with slow slipping.

Four hips were treated by subtrochanteric osteotomy. These cases were selected when malunion was incomplete, with obliteration of the epiphysis. External-rotation deformity in a movable hip gave an excellent result for the time being in these cases. Obviously, with the malposition of the epiphysis in this group, degenerative hip disease will eventually occur, even in those cases in which the present results are successful.

Even though the displacement of the upper femoral epiphysis is old or gradual in its occurrence, marked limitation of motion in the hip joint is frequently present. Although an increase in the range of motion does not satisfy the criteria given for the clinical classification, many of these cases show an increasing range of motion following the operative procedure (Table II).

The results of the open operation without wedge and with internal fixation showed that four (100 per cent.) of these patients had an increase in their range of motion after operation.

The patients with acute traumatic displacement of the epiphysis usually had marked limitation of motion before operation, as a result of the pain and muscle spasm, due to the trauma. In those in whom reduction was obtained by traction or gentle manipulation, five (83 per cent.) had an increase in their range of motion after operation; and one patient (17 per cent.), in whom aseptic necrosis developed, had a decrease in the postoperative range of motion.

Interestingly enough, of the patients upon whom internal fixation was performed without any attempt at reduction, four (25 per cent.) had a postoperative increase in their range of motion. Traumatic arthritis following the operative procedure developed in two of these cases, with decreasing range of motion. In seven (44 per cent.) of these cases a normal range of motion persisted, both before and after operation, and one patient had a persistent, equal, limited range of motion both before and after the operation.

Of the four patients upon whom subtrochanteric osteotomy was performed, two had a persistent, equal, limited range of motion both before and after operation. One had a postoperative increase in his range of motion, and one had a postoperative decrease in the range of motion.

Of all the operations performed—that is, in seventy-five hips—the normal range of motion persisted in eight (11 per cent.) both before and after operation. Five (7 per cent.) had a persistent, equal, limited range of motion before and after operation. Forty-five (60 per cent.) had a postoperative increase in their range of motion, and seventeen (22 per cent.) had a decrease in their postoperative range of motion.

The complications resulting from various operative procedures were four in number,—traumatic arthritis, failure of union at the osteotomy site, aseptic necrosis of the head of the femur, and a crushing injury to the head and neck resulting from a manipulative procedure (Table III).

The roentgenographic changes considered as indicative of traumatic arthritis are those in which there is a gradual or rapid loss of joint space; a generalized osteoporosis early in the postoperative period, and a subsequent loss of the subchondral bone; proliferative changes around the joint with deformity of the head of the femur and the acetabulum; and osteosclerosis of the articulating portions of the acetabulum and femoral head, with cystic degeneration. In certain cases it was difficult to state definitely whether all of the pathological changes demonstrated by roentgenogram were the result of traumatic arthritis alone, or whether they may have resulted from an associated aseptic necrosis, without serial roentgenographic evidence to substantiate its existence.

Aseptic necrosis is defined as a relative increase in the density of the femoral head with subsequent fragmentation and loss of substance, without early concomitant changes in the acetabulum and usually with a well-maintained joint space.

In eighteen of the seventy-five hips operated upon, traumatic arthritis developed. Obviously the greater proportion occurred in the group which had had open reduction; in approximately one third of these cases arthritis developed, whereas arthritis occurred in only 8 per cent. of the cases of internal fixation done blindly. The value of early recognition and early treatment is emphasized here. In spite of roentgenographic evidence of arthritis, two patients had good clinical results.

Two other cases have been added to this group, although the patients had received no previous therapy; arthritis developed and the patients consulted us primarily for the painful, stiff hip. They have been included in this study to demonstrate the spontaneous tendency for arthritis to develop, without treatment. Vitallium-cup arthroplasties were performed upon these two patients.

Aseptic necrosis developed in three of the cases. One patient has to date a full range of asymptomatic motion, but it is only six months since the operation. The area of aseptic necrosis seems to be localized at the superior margin of the head. In the reported case of aseptic necrosis following closed reduction with internal fixation, the head appeared dead prior to the nailing. Union occurred, however, and later a typical aseptic necrosis resulted. The authors feel that three of seventy-five hips operated upon (4 per cent.) do not constitute a high incidence of aseptic necrosis for operative procedures which can correct an otherwise certain disability.

Non-union of the epiphysis and the neck at the osteotomy site occurred in only one case. This was the result of inadequate fixation with a Smith-Petersen nail which was too short. It is a tribute to the procedure that failure to unite occurred only once.

The crushing of the head and neck of the femur is a complication which should not have occurred. Overzealous manipulation with the application of any force should not be employed in this group. This is a preventable complication.

The end results, both clinically and by roentgenogram, of the operative procedures in the twelve patients with bilateral hip involvement were essentially the same in both hips, even though a different procedure was done in each hip. Both hips did well or both did poorly in each case.

Table IV presents a correlation of the end results with the duration of symptoms. In our Clinic, the acute injuries are in a minority, so that the table is not of much value, except to point out that good or excellent results could be obtained some months after the onset of the lesion. The acute traumatic displacements, readily reduced and fixed internally by blind nailing, did produce the best results.

It has been observed in several patients in whom traumatic arthritis developed that, in serial roentgenograms, the joint space previously lost was re-established. This restoration of an essentially normal joint space was accompanied by relatively little improvement of the functional result. An explanation for this phenomenon is lacking, but possibly it results from a loss of the superficial layers of articular cartilage, with a retention of the germinal layer With later proliferation of the germinal layer, the joint space is re-established.

CONCLUSIONS

With careful selection of cases and the proper operative approach, the authors feel that open operative correction by transcervical osteotomy and internal fixation gives the best chances for good function of the hip joint. In the slipped upper femoral epiphysis with malunion, because of the re-establishment of a normal anatomical relationship, the chance of this good function persisting into later life is excellent. Sixty-eight per cent. of the hips operated upon by this method had good hip-joint function, some having been observed as

long as twelve years after the operation. We feel that this percentage justifies our continuance of this operative procedure.

Blind fixation of the epiphyseal line in the preslipped and early phases of slipping insures against the possibility of subsequent, more extensive, displacement. Such a procedure does not predispose the hip to the development of arthritis.

The two major complications arising as a result of the operations on the hip for this condition are traumatic arthritis and aseptic necrosis. Only 4 per cent. of the hips which were operated upon revealed roentgenographic evidence of aseptic necrosis; consequently it is not a frequent complication of the operation. Definite evidence of traumatic arthritis was present in 24 per cent. As this developed in two patients in whom no therapy had been attempted and in two in whom blind nailing had been performed, it has led the authors to conclude that the operative procedure is not the only factor contributing to this complication, but that some intrinsic predisposition toward this complication exists in this peculiar condition.

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DISCUSSION

Dr. Lewis Clark Wagner, New York, N. Y.: I should like to bring out a few points concerning these papers.

1. Early diagnosis probably would preclude all this discussion. I agree that in cases in which the diagnosis is suspected or arrived at early, where there is no slipping or a minimum of slipping of the epiphysis, a well-placed nail, transfixing the neck and the head on the affected side, would yield a cure in almost every case. It is important that there be no weight-bearing for at least six months in these cases, as the nail serves only to prevent further slipping until union of the epiphysis can progress in the usual manner.

2. Closed reduction should be attempted only in the acute traumatic case. I have often attempted to reduce the slipped femoral epiphysis under direct vision with the hip joint opened, and I have concluded that it cannot be reduced. One is apt to be deceived because, when the limb is internally rotated and abducted, it gives the appearance of reduction with lengthening of the neck. However, in the lateral roentgenogram, we find that no change has taken place.

3. When the narrowed joint space is noted in the old cases and degenerative changes are present in the articulation, nothing can be done except to hope for the best or to perform an arthrodesis of the hip. Arthroplasty may be tried, but I am reserving my opinion on that.

4. Subtrochanteric osteotomy, I feel, is the second choice for the treatment of badly slipped epiphyses. In patients with marked limitation of motion and the limb in external rotation, with or without flexion deformity, the surgeon, whose care is sought from three to five years after the initial symptoms, can hope only to salvage what is left and to let Nature take its course, after the deformity of the femur has been corrected and the limb has been placed in the attitude of good function, which is correction of the external rotation and the flexion-adduction deformity. Subtrochanteric osteotomy is probably best suited to the average surgeon.

5. I consider the wedge osteotomy of the neck of the femur the operation of choice. This operation should be limited to patients from eleven to fifteen years of age, whose slipping has been present from a few months to a year or over. It is most satisfactory when there has been up to 70 per cent. slipping of the head on the neck. We have had most gratifying results in over twenty cases in the last ten years. I am sure many surgeons have tried the wedge osteotomy, but have abandoned it because they did not follow through the treatment correctly. There are many technical difficulties.

This treatment seems to be most rational because, in these advanced cases, we see *an apparent disruption* of the circulation of the head of the femur,—circulation which, at its best, is inadequate. At this stage, union apparently has begun to take place with the hip in the deformed attitude, in an attempt at normal restoration of circulation. To try to replace the head of the femur by division of the epiphyseal line would add trauma to the already impaired circulation of the head. The neck of the femur has ample circulation so that, by removal of a section of bone through the cancellous area, the circulation of the impaired epiphyseal

plate is not disrupted. By this method, we have restored the anatomical position of the head of the femur, corrected the coxa vara, and given Nature the best chance to aid in the healing of the affected parts.

I am not unmindful of the pitfalls and hazards that may arise, should not extreme care, gentleness, and diligent attention to detail be followed in this form of treatment.

Dr. Harold E. Crowe, Los Angeles, California: Since I have come to accept as gospel the work of Dr. Eugene Wolcott on the blood supply of the capital femoral epiphysis, I do not do osteotomies through the neck of the femur. If the gentlemen who have presented operations today are able to do so without injury to the periosteum, great credit is due them as surgeons. Until I feel able to do this surgery more easily, I do not plan to undertake this type of operation.

We must have large numbers of statistical facts, and Dr. Badgley has given us these facts. Undoubtedly in a large scientific institution it is all right to have 32 per cent. of bad results, but in the town in which you practise, one case of aseptic necrosis would be a major catastrophe. I have not had the opportunity to see the roentgenograms of Dr. Martin's cases, but I have looked over Dr. Badgley's roentgenograms, as displayed in his scientific exhibit at this meeting. I found only one hip in which I felt a true normal had been restored. All of the hips presented in these roentgenograms will undergo major degenerative changes within twenty years.

While it is wonderful to have given a sixteen-year-old boy twenty years of useful hip function, at age thirty-six, when the man has reached the high point of productive activity, a degeneration of the hip with pain sufficient to stop his activities will be a major catastrophe. None of us can follow a thousand individuals with this type of illness through a twenty-year period, since none of us can live that long. It must be the accumulated effort of many men to produce a series of one thousand cases with a twenty-year follow-up; and, until that has been done, I feel that most of us should use the procedure given by Dr. Vernon P. Thompson in 1937, and published in 1943 as the V-shaped telescoping osteotomy (*Archives of Surgery*, 46: 772, 1943). He produced excellent hips, without signs of such degeneration as we have seen in the exhibit.

Dr. Alan DeForest Smith, New York, N. Y.: I would like to correct the statement which Dr. Badgley made about the practice at the New York Orthopaedic Hospital in regard to open reduction of the slipped epiphysis. It is true that we made the statement several years ago that we did not approve of this operation. We have found, however, that it is necessary to do an open reduction by an osteotomy through the neck of the femur in severe cases, but we confine the operation to the most extreme deformities. In the less severe displacements, we still prefer to correct the internal rotation and adduction by a subtrochanteric osteotomy. Fortunately, most of our cases are seen in the early stages, when correction of the deformity is not necessary.

The operation which we have used for some time to effect an early closure of the epiphyseal line is to expose the neck of the femur and to cut a small window, about one centimeter square, in the neck, close to the margin of the head. Through this a drill is passed across the epiphyseal line into the head in several directions, and a small sliver of bone is placed in each drill hole. This produces bony union between the head and neck in an average of about eight weeks, at which time it is possible to get the patient up with crutches. We do not immobilize the hip after the operation.

Dr. J. Albert Key, St. Louis, Missouri: In 1922, I reviewed all the cases of slipped epiphyses we had had at the Massachusetts General Hospital. At that time we showed this as a migration of the epiphysis. It happens during a period of rapid growth. This "new" operation that is being reported has been done all over the country for twenty years. When Smith-Petersen introduced his nail, that was used. You can only reduce the displacement by shortening the neck. The head is found on the posterior portion of the neck and is united by bone. When you get enough bone out to permit reduction, you usually find a ridge of bone on the posterior and inferior borders of the neck, and this must be removed.

I had two cases of aseptic necrosis before the Smith-Petersen nail was introduced. I have had no case since, but have had one case of ankylosis. I have not done so many operations as Carl Badgley and his associates, but most of the results have been good hips. They are going to be good hips at sixty-five. If you do a subtrochanteric osteotomy and do not correct the position of the head, an arthritis will be produced by incongruity and not by nutritional changes. This may occur as a result of an operation done twenty years previously. Some of these are so markedly rotated externally that I have pulled off the greater trochanter, trying to reduce the displacement.

This is the operation of choice in my hands. You will not get aseptic necrosis in enough cases to make it worth while to do any other procedure with which I am familiar. I believe you will get permanently good hips, if you do the operation fairly well.

Dr. William T. Green, Boston, Massachusetts: I would like first to comment on Dr. Martin's paper. At the meeting of the American Medical Association in Cleveland in 1944, we described in detail a technique which has little variation from that described by Dr. Martin. I would like to emphasize one or two points. One is that there is what amounts to a mesentery on the inferior aspect of the neck of the femur—

the retinaculum of Weitbrecht—which contains a large part of the vascular supply for the head of the femur In slipped epiphysis, as the neck migrates forward and upward, the superior cervical vessels are interrupted and the inferior cervical vessels of the retinaculum are shortened, but maintain their continuity. If the vessels remain in this shortened position for any length of time, they adapt themselves to this new length. However if the head is pried into position, they must necessarily be stretched beyond their adaptive length, occluding their lumina, which may well precipitate aseptic necrosis of the head. The problem, then, is a little more than removing enough bone to restore alignment and to be able to pry on the head. One must remove enough bone from the neck to place the head in position without tension on the inferior vessels. A careful subperiosteal dissection for exposure of the neck is important, but in this the big thing is to preserve the inferior vessels.

I would like to call attention to the results obtained in a group of cases which were treated by traction to the extremity in internal rotation, followed by a hip spica, which in turn was followed by counterpoised traction with motion; this was called the traction-spica-traction method. These cases were reported in the paper referred to, which was published in the *Archives of Surgery* in January 1945 (vol. 50, pp. 19-32). The indications for the use of this method were outlined, and the results obtained were as good as those in any group with which we are acquainted.

Dr. Paul H. Martin (closing): In my paper I was mainly attempting to make two points. The first concerns the dangers of manipulation. I think most of us have at some time been intrigued with that form of intervention; but it is too dangerous, even if unsuccessful. Also, many of the poor results which follow open reduction may be due to the trauma of a preliminary attempt at reduction by manipulation. Therefore, if we cannot get a large series of cases to study which have had no preliminary manipulation, I do not see how we can get any accurate idea of the results of operative reduction.

Dr. Key has said that open reduction is nothing new and has been done all over the country for twenty years. Yes, open reduction has been done all over the country, probably by most of you, during the last twenty years. But how? And with what results? Too many cases of aseptic necrosis, too much traumatic arthritis, too many poor results. Something has been lacking in the method, or rather in the technique.

The second point I tried to establish in my paper was the extreme importance of preserving the essential attachments of the epiphysis at operation. From the picture Dr. Wagner showed, it was not clear to me that he was talking about the same thing I was talking about. In the slides he used to illustrate his discussion, the periosteum had not been reflected and preserved in the way which we think is essential to avoid injury to the blood supply. Nor was this evident in the slide which Dr. Badgley showed. When we come to appreciate the importance of the periosteal blood supply of the epiphysis, I am sure that the results of open reduction will improve.

I wish to thank the gentlemen who discussed our papers.

SUMMARY OF RESULTS OF BONE-GRAFTING FOR WAR INJURIES

BY LIEUTENANT COLONEL REGINALD C. FARROW

Medical Corps, Army of the United States

The purpose of this paper is to record the experience obtained in the transplantation of autogenous bone for the treatment of 156 consecutive cases of fracture of the long bones with non-union or limited union, sustained as a result of war injuries. The patients in this series were treated in the Section of Orthopaedic Surgery of Deshon General Hospital, Butler, Pennsylvania, during the years 1943 to 1946. The facilities for treatment were those of the average named Army General Hospital in the Zone of the Interior, and were of outstandingly high quality in all respects. The clinical work was performed by several fully qualified orthopaedic surgeons, and the results are to be viewed as those of group effort.

These patients were received at Deshon General Hospital from six weeks to several months after the initial injury overseas and, with the exception of eighteen patients who were operated upon within a few months of the closing of the Hospital in the spring of 1946, they remained for the entire period of definitive treatment, thus permitting an evaluation of the end results. Compound fractures had occurred in 80 per cent. of the cases, and almost all were solely injuries of the bones and soft tissues, not accompanied by peripheral-nerve or vascular injury.

An estimated 8,000 fractures of the long bones were treated at this Hospital during its period of activity, and the incidence of non-union and limited union can thus be estimated roughly as about 2 per cent.

The diagnosis of non-union was made by conventional criteria. In many cases, with loss of bone substance and a gap between the fragments, the diagnosis was obvious. When an acceptable reduction of the fracture existed, the presence of false motion at the fracture site at the end of six months, plus roentgenographic evidence of failure of union, was considered to indicate non-union. However, it was found that the arbitrary six-month period could often be revised downward for fractures of the tibia, where non-union might be strongly suspected at four and one-half or five months; and very frequently it could be revised upward for fractures of the femur, which often united at eight or nine months by closed methods.

The timing of operative intervention, in a large number of cases, was dependent upon the complete healing of soft-tissue wounds and the restoration of skin, adequate in quality and quantity, at the level of the fracture site. In instances of soft-tissue deficiency in the area of approach to the bone-graft operation, the appropriate soft-tissue plastic procedures were carried out meticulously, preliminary to bone surgery. The misfortunes attending disregard of this fundamental rule were observed in a few instances early in the series.

No postoperative infection at the site of the donor bone occurred. Postoperative fracture of the donor tibia occurred in four instances, and the application of a tibial caliper brace was employed frequently in the latter part of the series to prevent this complication.

All patients received penicillin postoperatively for two weeks, or longer when indicated.

RESULTS

A total of 156 cases were treated by autogenous bone-grafting,—in 137 instances for non-union, and in 19 instances for limited union.

Of the 137 cases of non-union, the end results are known in 119. Of these, the procedure was successful in securing union in 104 cases (87.4 per cent.). The procedure failed in fifteen cases (12.6 per cent.). Eighteen cases were lost track of before the end results could be judged.

TABLE I

Results of Bone Grafts for Non-Union in Entire Series

Location of Graft	No. of Grafts	End Results Known	Successful Results		Failures	
			No.	Per cent.	No.	Per cent.
Humerus	13	10	9	90	1	10
Radius	13	8	6	75	2	25
Ulna	21	17	15	88.2	2	11.8
Metacarpals	27	27	27	100	0	0
Femoral neck	5	4	4	100	0	0
Femur	13	10	7	70	3	30
Tibia	38	36	29	80.6	7	19.4
Medial malleolus	7	7	7	100	0	0
Totals	137	119	104	87.4	15	12.6

Of the fifteen failures, eight were complicated by postoperative infection, and in seven the wounds were clean postoperatively. A total of eighteen postoperative infections occurred in the entire series (11.5 per cent.).

The results for the complete series are summarized in Table I.

The inclusion of non-union of the metacarpals and medial malleoli, for the sake of completeness in a consecutive series, gives a percentage of successful cases which is *weighted unduly by non-unions that respond readily to bone-grafting and offer relatively* little technical difficulty. Table II summarizes the results when the metacarpals and medial malleoli have been excluded, and gives a truer picture of the findings in the more difficult types of cases. In this smaller group, comprising non-union of the humerus, radius, ulna, femoral neck, femur, and tibia, the end results are known in eighty-five cases, of which seventy (82.4 per cent.) were successful and fifteen (17.6 per cent.) were failures.

FINDINGS IN INDIVIDUAL GROUPS

Humerus

Thirteen cases of non-union of the humerus were treated. The end results could be determined in ten, of which nine (90 per cent.) were successful and one (10 per cent.) was a failure.

There was a high incidence of gross comminution and loss of bone substance in this group; and, in all of the thirteen cases, the fracture site was near one end of the bone, seven being in the proximal fourth and six in the distal fourth. They commonly presented an especially difficult technical problem in the anchoring of the graft to the short fragment, which often was not long enough to permit the use of an onlay graft. This difficulty was

TABLE II

Results of Bone Grafts for Non-Union, Excluding Metacarpals and Medial Malleoli

Location of Graft	No. of Grafts	End Results Known	Successful Results		Failures	
			No.	Per cent.	No.	Per cent.
Humerus	13	10	9	90	1	10
Radius	13	8	6	75	2	25
Ulna	21	17	15	88.2	2	11.8
Femoral neck	5	4	4	100	0	0
Femur	13	10	7	70	3	30
Tibia	38	36	29	80.6	7	19.4
Totals	103	85	70	82.4	15	17.6

usually overcome, in the proximal fourth, by impounding a tibial graft into the head and neck, and onlaying the distal portion of the graft to the shaft with metal-screw fixation. Any existing gap was closed by shortening. In the distal fourth, an intramedullary peg of tibial cortex was used in three cases. The undesirable features of intramedullary grafts in general were fully appreciated, but it was felt that the firm fixation afforded by this type of graft in this location offset its disadvantages. In the remaining three cases in the distal fourth, it was possible to use onlay grafts.

The one failure was in a fracture of the proximal fourth, and was secondary to postoperative infection.

Radius

Thirteen cases of non-union of the radius were treated. The end results could be determined in eight, of which six (75 per cent.) were successful and two (25 per cent.) were failures. The usual procedure was a tibial onlay graft with metal-screw fixation.

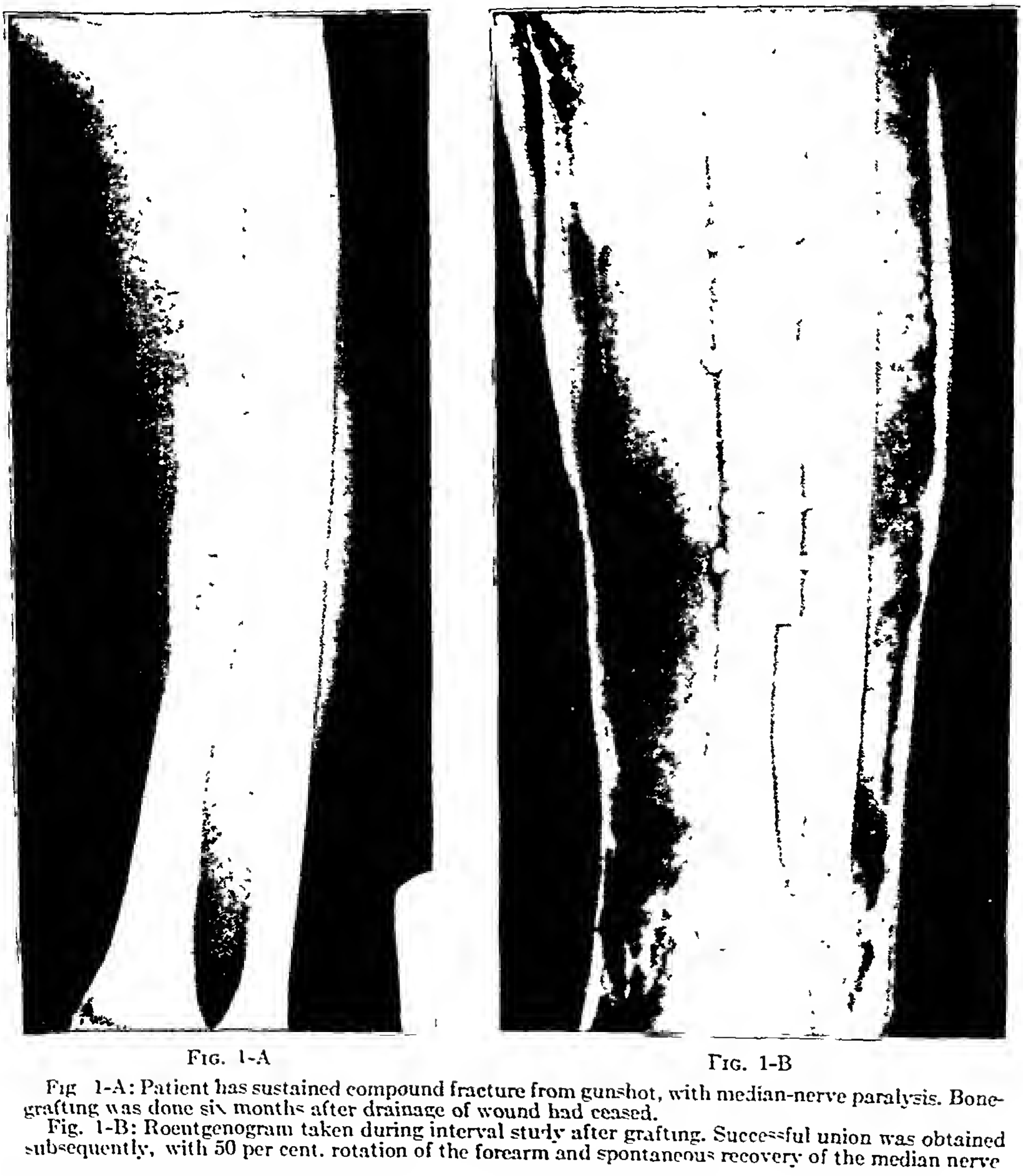

Fig. 1-A Fig. 1-B

Fig. 1-A: Patient has sustained compound fracture from gunshot, with median-nerve paralysis. Bone-grafting was done six months after drainage of wound had ceased.

Fig. 1-B: Roentgenogram taken during interval study after grafting. Successful union was obtained subsequently, with 50 per cent. rotation of the forearm and spontaneous recovery of the median nerve

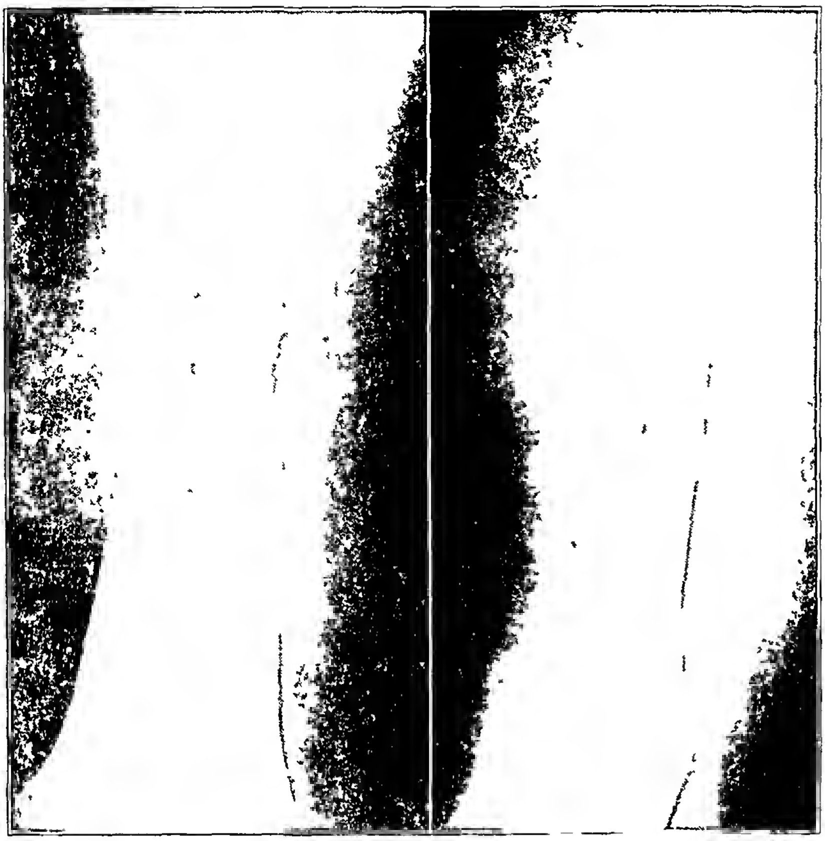

Fig. 2-A

Fig. 2-B

Fig. 2-A: Patient had compound fractures of femur, tibia, and radius. Successful secondary closure of all wounds was carried out overseas two weeks after injury. All fractures united, but the femur had limited union. Refracture of femur occurred while patient was in ischial caliper brace. Traction and suspension were resumed, and limited union was obtained.

Fig. 2-B: Roentgenogram taken after bone-grafting. Knee motion was from 180 to 85 degrees.

Of the two failures, one was due to an immediate gross postoperative infection, necessitating the eventual removal of the graft. The second was probably due to faulty technique. Another grafting procedure was done subsequently, the result of which is not known.

Ulna

Twenty-one cases of non-union of the ulna were treated. The end results could be determined in seventeen cases, of which fifteen (88.2 per cent.) were successful and two (11.8 per cent.) were failures.

These fractures commonly presented gross loss of bone substance, with resulting bone gaps up to two inches. The ease of exposure, however, rendered them technically simple to deal with. A tibial onlay graft was used most frequently, a tibial inlay graft was used in a few cases, and a sliding onlay graft was employed in one instance. Metal-screw fixation was preferred, but poor quality and caliber of bone occasionally prevented its use, and loops of stainless-steel wire had to be resorted to. Wire had the disadvantage of offering less security, and tended to be irritating afterward in its subcutaneous location. Wire was the method of fixation in one of the failures.

The two failures occurred in the same patient. A large bone defect was bridged with a tibial onlay graft, which failed to unite with the proximal fragment. The failure was probably due to the inability of the operator to deal effectively with a proximal fragment of bone of poor quality. A second attempt failed in the same area. A third procedure was carried out, the end result of which is not known.

Metacarpals

Twenty-seven cases of non-union of a metacarpal were treated routinely by the inser-

›n of an intramedullary dowel of tibial cortex. Union was obtained in every case. A ld transient infection occurred in one case, but it did not interfere with the final ult.

Femoral Neck

Five cases of non-union of the neck of the femur were treated. The end results could .e determined in four, all of which were successful.

The method of treatment employed was the placing of a bone dowel through the femoral neck, across the fracture site. The hip was opened in one case, the fracture site was visualized, the fracture was reduced, and a portion of the fibula was driven through a drill hole under direct vision. In another case, two small grafts of tibial cortex were placed ol· ·ily. Postoperative roentgenograms showed one graft to be too short to cross the fracture site, but union was obtained after considerable delay. In the remaining two cases. : dowel of tibial cortex, one-half inch in diameter, was placed blindly through the neck.

FIG. 3-A FIG. 3-B

Fig 3-A: Compound fracture resulted from gunshot. Successful skin-grafting was performed overeas, bone-grafting was done four months after completion of the skin graft.

Fig. 3-B: Roentgenograms taken during interval study after bone-grafting. Low-grade infection of wound supervened. Devitalized bone and part of the metal were removed six months after grafting. The remaining metal was removed nine months after bone-grafting. Complete wound healing and successful union had occurred eleven months after grafting.

TABLE III

PRESENCE OF INFECTION AFTER BONE-GRAFTING

Location of Graft	No. of Patients Operated Upon	Postoperative Infections Within Group		Failure of Procedure Caused by Postoperative Infection
		No.	Per cent.	
Humerus	14	2	14.3	1
Radius	13	1	7.7	1
Ulna	21	2	9.5	0
Metacarpal	27	1	3.7	0
Femoral neck	5	1	20	0
Femur	21	2	9.5	2
Tibia	48	9	18.8	4
Medial malleolus	7	0	0	0
Totals	156	18	11.5	8

Femur

Thirteen cases of non-union of the femur were treated. The end results could be determined in ten cases, of which seven (70 per cent.) were successful and three (30 per cent.) were failures. A single tibial onlay graft with metal-screw fixation was the method usually employed. Two of the failures were due to postoperative infection. The third failure was in a femur of extremely poor vitality. There was no evidence of bone regeneration after grafting, and the graft finally broke. A double onlay graft would probably have produced a better result.

It is believed that the small number of femora which came to operation is a reflection of the conservative handling of this fracture. In many instances, an apparent failure of union at six months was converted into union at eight or nine months by continued traction and suspension. It is felt that, by using the intervening time to promote knee action, these patients were made ambulatory, with a solid femur and an adequate range of knee motion, earlier than if they had been subjected to a bone-grafting procedure at the end of six months.

Tibia

Thirty-eight cases of non-union of the tibia were treated. The end results could be determined in thirty-six cases, of which twenty-nine (80.6 per cent.) were successful and seven (19.4 per cent.) were failures.

A variety of methods were necessary to deal with the complex fracture patterns encountered. The most common type was an inlay graft from the opposite tibia, applied to the medial surface. It was desirable to fix the graft so securely by mortising that metal-screw fixation was unnecessary, and among the benefits of this method was a considerable saving of operating time. However, metal-screw fixation had to be used in many instances. The graft was applied to the lateral surface of the tibia in several cases early in the series; this area was abandoned subsequently in favor of the medial surface, because of the ease of approach. Sliding inlay grafts were used when the fracture site was conveniently located in the proximal or distal portion. Combinations of onlay and inlay grafts, plus the use of bone chips, were devised to bridge the grossly comminuted fractures with loss of bone substance. The ingenuity of the operator was sometimes taxed severely to accomplish both fixation and restoration of continuity in these grossly shattered tibiae. Osteotomy of the fibula sometimes permitted a better approximation of the tibial surfaces, by allowing shortening to close a small persistent gap. The supportive effect of an intact fibula, however, was not to be dispensed with lightly. A combination of inlay and intramedullary graft was used successfully to bridge a gap in one instance.

TABLE IV

RESULTS IN SIXTEEN CASES OF FRANK OSTEOMYELITIS AND NINE CASES OF LONG-CONTINUED DRAINAGE, AFTER BONE-GRAFTING

Results	Osteomyelitis		Long-Continued Drainage	
	Without Postoperative Infection	With Postoperative Infection	Without Postoperative Infection	With Postoperative Infection
Union obtained	3	4	6	1
Procedure unsuccessful	1	2		1
End result not known	6		1	
Totals	10	6	7	2

The procedure failed in seven instances:

In one case there had been drainage from the site of fracture for eight months after injury. Bone-grafting was performed 1.4 months after the establishment of a dry wound. A gross postoperative infection followed, with disruption of the graft.

An osteomyelitis had followed injury in the second case, with gross loss of soft tissue in the region of the fracture site. The osteomyelitis responded to conservative treatment, and the soft-tissue defect was covered successfully by a pedicle skin graft, nine months after injury. Bone-grafting for non-union was performed 1.8 months after the completion of the skin graft. Eight weeks after bone-grafting, a slight amount of drainage from the wound was present, and a slow, progressive breakdown of the wound ensued. Multiple sequestrectomies of the host bone were performed, but in spite of the active infection present, the graft remained firmly in place, appeared to be uniting, and was allowed to remain. The outcome in this case is not known.

In the third case, bone-grafting was performed 5.8 months after a successful skin graft. An immediate gross postoperative infection followed the bone-grafting.

In the fourth case the removal of a protruding bone fragment at another hospital was required, three months after injury. Drainage ceased two months later. A small area of scar was excised; fresh skin edges were approximated; and healing was obtained. Bone-grafting was performed 0.6 month after healing of the skin wound. Slight drainage from the wound was noted two weeks after operation, but this gradually ceased as a result of penicillin therapy. In a period of nine months after operation the fracture became firmly united, but a low-grade osteomyelitis continued and several sequestrectomies, in areas relatively remote from the graft, were performed. It is felt that the osteomyelitis was influenced adversely by a poorly timed operation, and the case is classed as a failure.

Osteomyelitis was present for eighteen months after injury in the fifth case, necessitating two sequestrectomies at other hospitals. The bone-graft procedure had been done

TABLE V

RELATION OF POSTOPERATIVE INFECTION TO WAITING PERIOD IN SAMPLE GROUP OF SEVENTY-TWO CASES

	Length of Waiting Period			
	One to Three Months	Three to Six Months	Six to Eight Months	Total
Without postoperative infection	9	31	18	
With postoperative infection	6 (40%)	8 (20.5%)	0	
Totals	15	39	18	72

through a tense, poorly nourished, scarred skin area, which broke down after operation and exposed the area of grafting. It is felt that the failure to provide adequate soft-tissue covering was the dominant error in this instance.

The sixth was a clean case, and failure of union was probably due to poor technique.

A history of fracture of the tibia in infancy, possibly at birth, was obtained in the seventh case. Union, with a marked lateral bowing deformity, was obtained, apparently after the passage of considerable time. Spontaneous fracture of the same tibia occurred during a forced march in Africa. Bone-grafting was performed, without correction of the bowing deformity, and failure resulted. A second bone graft, with correction of the deformity by osteotomy, was successful.

Medial Malleolus

Seven cases of non-union of the medial malleolus were treated, and union was secured in all. Each was treated by the insertion of a dowel of tibial cortex across the fracture site. In most instances, the fracture line could not be obliterated completely, and it was necessary to fill the space with bone chips.

LIMITED UNION

Limited union is defined as union occurring in fractures with loss of bone substance, in which the consolidation takes place in a relatively small area of the fracture site, as seen in cross section; the fracture is thus firm only across a strut. The possibility of the eventual deposition of sufficient amounts of additional effective bone was considered to be remote, and the likelihood of subsequent refracture was considered to be great.

The nineteen cases of limited union in this series included ten tibiae, eight femora, and one humerus.

The findings at operation almost invariably proved the need for operation in these cases. The bone defects were found to be filled with dense, adult-type fibrous tissue, in which the further laying-down of bone appeared to be highly unlikely. After excision of the scar tissue, the bone defect was seen to be much more extensive, as a general rule, than had appeared by roentgenographic study. Particularly in defects which were spiral in character, roentgenograms usually failed to demonstrate, in routine projections, the full extent of the deficiency.

The operative procedure involved complete excision of scar tissue from all the ramifications of the defect, freshening of the defect to raw bone, and filling it with bone chips from the ilium or with a tibial graft fashioned to fit snugly. In two instances, it was necessary to complete the fixation of a tibial graft with one metal screw.

There were no postoperative complications in this group, and in all cases, approximately normal bone caliber at the fracture site was restored.

INFECTION

A total of eighteen patients in the entire series of 156 cases suffered postoperative infection, of major or minor degree, following bone-grafting (Table III). Of these infections. nine were severe, causing failure of the procedure; six were moderate; and three were mild. Of the nine moderate and mild infections, the bone graft was successful in spite of the infection in seven cases, and the results are not known in two.

The gravity of this complication makes pertinent an inquiry into the background in these cases. Eighty per cent. of the patients in the entire series had originally had compound fractures, sustained in wartime in combat areas. Varying degrees of soft-tissue damage accompanied the bone injury, and the presence of bacterial contamination may be suspected. More specifically, sixteen patients showed frank osteomyelitis on admission; in these cases, sequestrectomy was performed at some time prior to bone-grafting. Nine patients had had long-continued drainage from the fracture site; in them, some degree of

osteomyelitis was to be suspected. Eight of the postoperative infections after bone-grafting occurred in this combined group of twenty-five cases. (Table IV shows the outcome in this group.)

There is considerable controversy as to the optimum time for bone-grafting in a case of non-union with previous infection. Before the sulfonamides and penicillin were available, a conservative attitude was conventional; and a considerable length of time, usually from six to twelve months, was allowed to elapse after the wound had healed before operation was undertaken. Under penicillin protection, there has been an appreciable tendency to shorten the waiting period, and what now constitutes a reasonable and safe waiting period is far from clear. In the present series, the waiting periods have ranged from one to eight months; and, in a portion of this series, it is possible to study and record the incidence of infection after bone-grafting in relation to the waiting period.

A sample group of seventy-two cases within the series lends itself to study; these were the only cases in which the record bore a notation of the exact date upon which a previously draining wound was considered to be dry and healed, thus permitting a precise computation of the waiting period. Within this sample group, the waiting periods ranged from one to eight months.

In Table V is recorded the incidence of postoperative infection in waiting periods of varying lengths. Fifteen patients were operated upon after intervals of from one to three months; the rate of postoperative infection was 40 per cent. in this group. Thirty-nine patients were operated upon after a wait of from three to six months; the rate of postoperative infection was 20.5 per cent. in this group. Eighteen patients were operated upon after intervals of from six to eight months, with no postoperative infections.

This series of cases is not large enough to justify definite conclusions as to the optimum waiting period which should precede bone-grafting in a case of non-union with previous infection. At the same time, it is suggested that it may be unwise to allow penicillin protection to replace unduly a waiting period of adequate length. The balance to be maintained between these two factors may well be the key to success in operations for this type of case. What may be considered an adequate waiting period in conjunction with penicillin coverage is not yet clearly established, and further studies of this nature will be needed.

INTERNAL CONTACT SPLINT *

BY G. W. N. EGGERS, M.D., GALVESTON, TEXAS

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The internal fixation of fractures has a definite, but limited, field of application in the treatment of fragment displacement. The closed method of treatment of fractures has been accepted as the most desirable, with splint, casts, or controlled traction to maintain the reduction. However, a certain number of fractures present problems, in the solution of which operative reduction and direct fixation of the fragments offer reasonable help.

Improvement in operative technique and a better appreciation of the physiological reaction of the low-metabolic processes of bone permit a reasonable understanding of surgical fracture repair. The introduction of metals with decreased chemical or electrolytic reaction has improved the use of foreign material in the surgical treatment of fractures.

The clinical and microscopic observations of fracture ends of fragments of bone have shown variable absorption of the fracture surface. The inactive area of devitalized bone is absorbed, which permits the viable bone of each fragment end to come into contact when proper reduction has been carried out. The contact is accomplished by the longitudinal muscle thrust in closed reductions. When direct contact of the fragments is prevented by any mechanical device, union of the fracture may be delayed or non-union may result. The clinical observation of a fractured tibia with an intact fibula has been an experience of many in cases of delayed union or non-union. Another observation has been the appearance of the line of absorption between the fracture ends of the fragments of bone, held in position by the usual type of commercial plate. The immobilization is complete, and the plate actually keeps the fragment ends apart by a distance equivalent to the absorbed portion (Fig. 1). The result may be delayed union or non-union, and often the plate will bend or break (Fig. 2). By examining the fracture site, we can see bony union attempted or accomplished by those portions of the fragment ends actually in contact.

In an effort to eliminate this factor of non-contact in many fractures on which plates have been used, and to reproduce the contact of the fragment ends as observed in closed reduction, the slotted type of plate was designed (Fig. 3). The plate is not applied to the fragment ends, as is the usual metal plate. Four screws are used in the slotted plate; the screws are applied as far distant from the fragment ends as possible and thus do not contribute additional trauma to the damaged area. In addition, the gliding slotted plate is not completely immobilized, nor is it loose. Actually, it permits controlled longitudinal motion when the screws are not set tightly. Thus, the muscle tone which produces a longitudinal thrust on the bones is permitted to function and to maintain the fragment ends in constant contact during the recovery period. In this manner, the fragments are allowed to maintain the mechanical and physiological apposition which is conducive to bony union (Fig. 4).

Application of the slotted plate, which the author prefers to call the internal contact splint to emphasize the fact that it is not applied firmly to the bone, is technically not so difficult as plate immobilization. The surgeon does not have to apply oblique fixation screws across the fragment ends of the bone or to struggle for perfect contact before placing screws in both fragments. The splint is placed in the fractured area along the longitudinal axis of the shaft and the four screws are inserted, two on each side of the fracture site, with a space between the screws and ends of the slot. The fragment ends can then be placed in close contact. When anaesthesia ceases, the tone returns to the muscle, and the

* Read at the Annual Meeting of The American Academy of Orthopaedic Surgeons, Chicago, Illinois, January 29, 1947.

FIG. 1

Absorption of the fragment ends, twelve weeks after operative reduction.

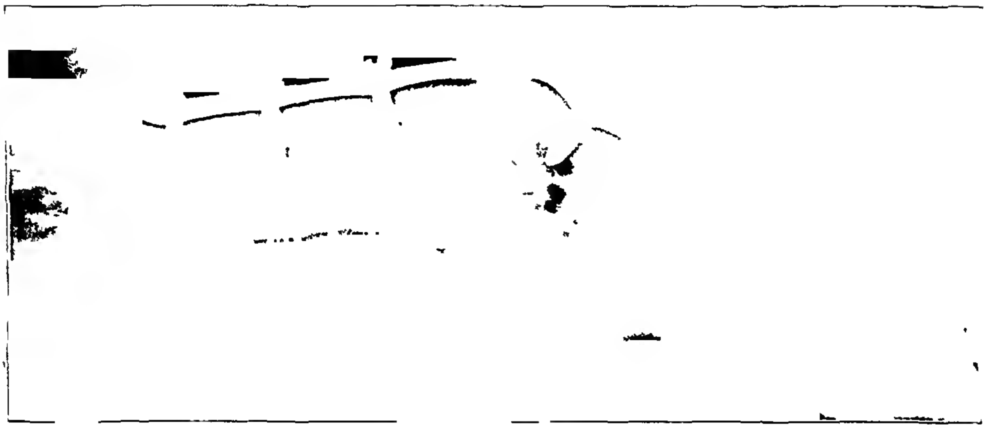

FIG. 2

Plate has broken. Note pressure atrophy of cortex due to tight plate, lack of osseous activity adjacent to the plate, and attempted union where contact of bones is present. Screws were short, but provided sufficient security.

longitudinal forces cause the ends to remain in constant contact during the healing period. If absorption of the fragment ends takes place, the deficiency is automatically obliterated, as in the closed reduction, and a mechanical and physiological situation favorable for union is created (Figs. 5-A to 5-H, inclusive).

The contact splint is useful in fracture of the shaft of a bone in an adult.

The care after open reduction is supportive, as would be required in the same fracture by the closed method. Earlier mobilization of joints is practised, and muscle activity in the fracture area is initiated during the first week after operation.

The extensive metal fixation of fractured bones is not physiological, and splinting is only a means to normal restoration of function. Supportive metal is not a substitute for the normal physiological repair of bone.

Some of the advantages of the contact splint are listed:

1. The fragment ends are easily placed together in exact approximation; the muscle pull will maintain the desired contact. Placing the screws in the bone is, therefore, easier.

2. Oblique fixation screws across the fractured ends are eliminated;

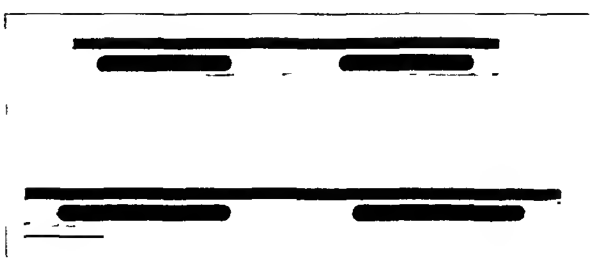

FIG. 3

Four-inch and five-inch splints. Six-inch and three-inch sizes (one slot and two slots) are also used

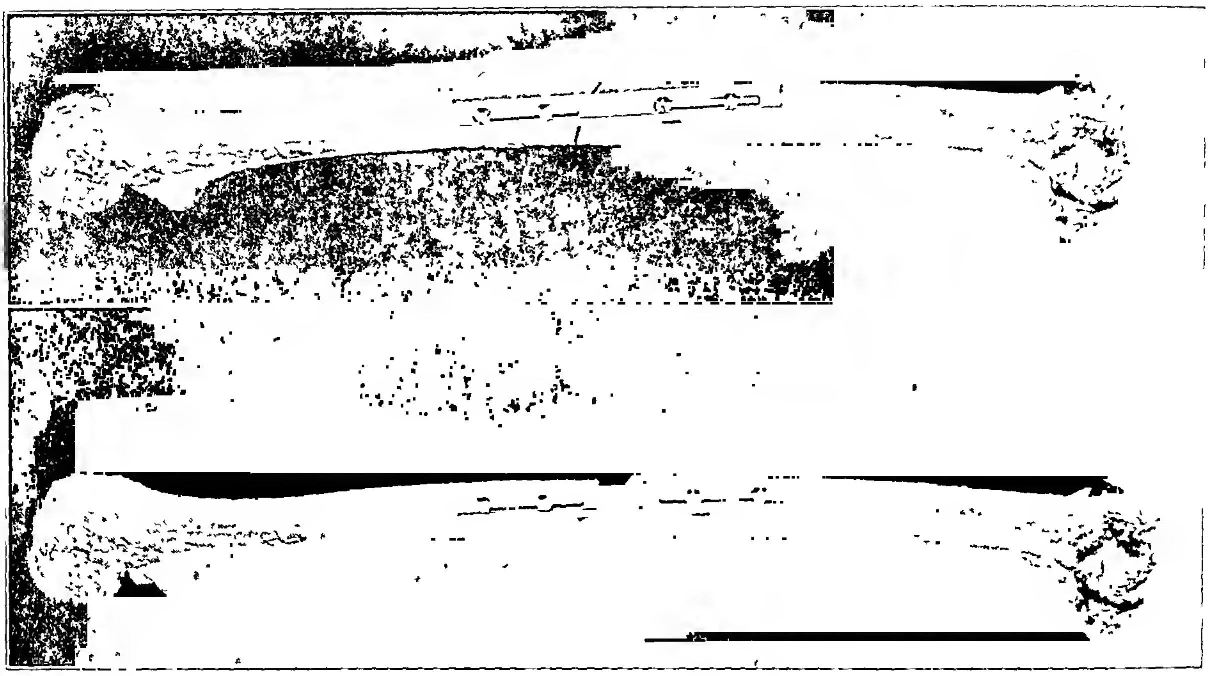

FIG. 4

Splint applied, showing longitudinal motion permitted. This gliding motion must be permitted to continue throughout the entire period of recovery. The screws should not be tightened.

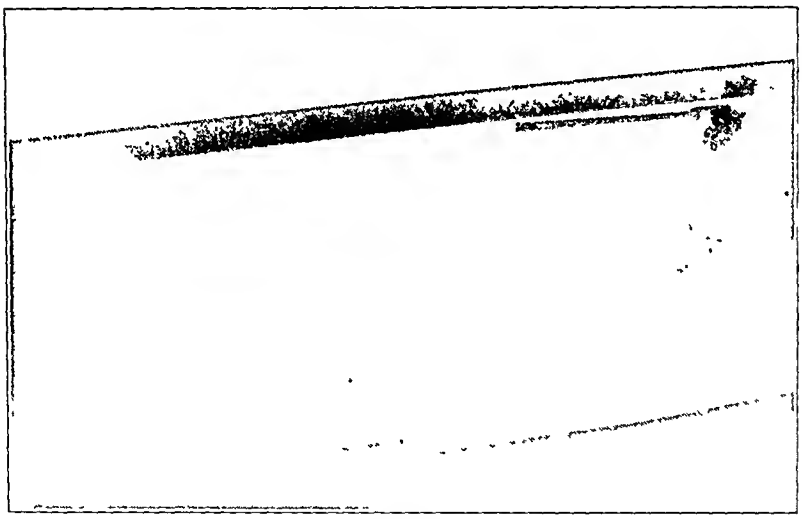

FIG. 5-A

Roentgenogram of fracture, two weeks after injury. Traction and closed reduction have failed.

and the fragment ends d not receive additional surgi cal trauma.

3. Impaction of th fragment ends is not desir able, physiological, or neces sary.

4. Bone absorption o the fragment ends is auto matically compensated fo by longitudinal muscle tone constant contact during th healing period is thus ac complished.

5. Fewer screws ar necessary for controlled fixa tion; therefore, less bon trauma occurs.

6. The splint is flat, and pressure on the bone and periosteum is minimal.

7. Contact is accomplished with the least mechanical difficulty by permitting longitudinal motion in one or both ends of the splint.

8. As the irregular fragment ends are held in contact by muscle tone, the stabilit of the fracture is secure and torsion is controlled because the plate locks, due to physica forces.

9. There is less stress on the splint to break or bend it at the fracture site because the space between the fragment ends of the bone, due to absorption, i eliminated.

10. Pressure in excess of eighty pounds has been applied repeatedly in the experimental laboratory to the long axes of bones, with no detrimental effect on the stabilit of the fracture site when the fragments are held in place by the splint.

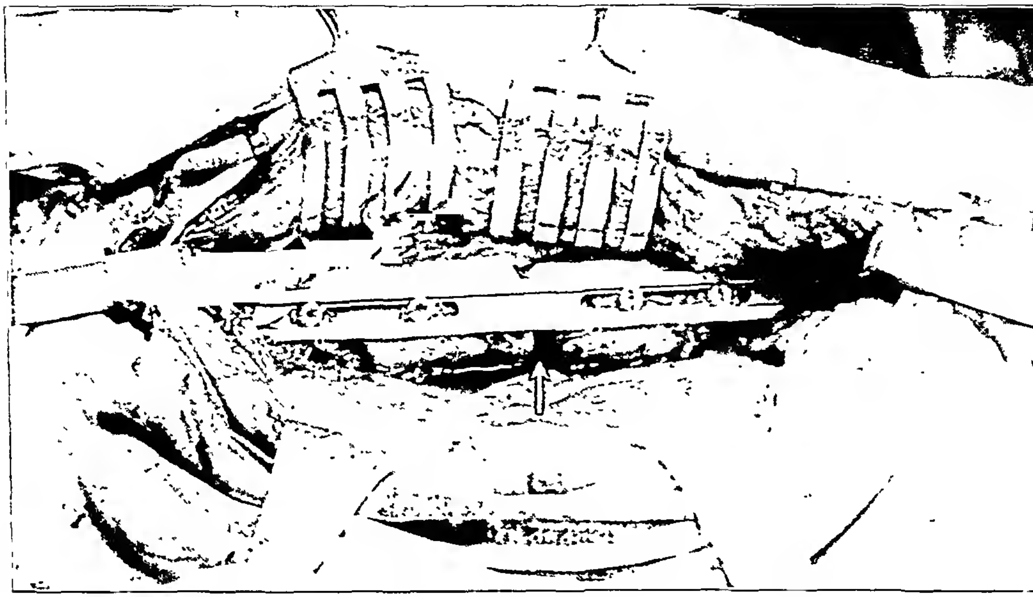

Fig. 5-B

Operative reduction and application of splint. Traction on extremity shows longitudinal mobility of the fragments.

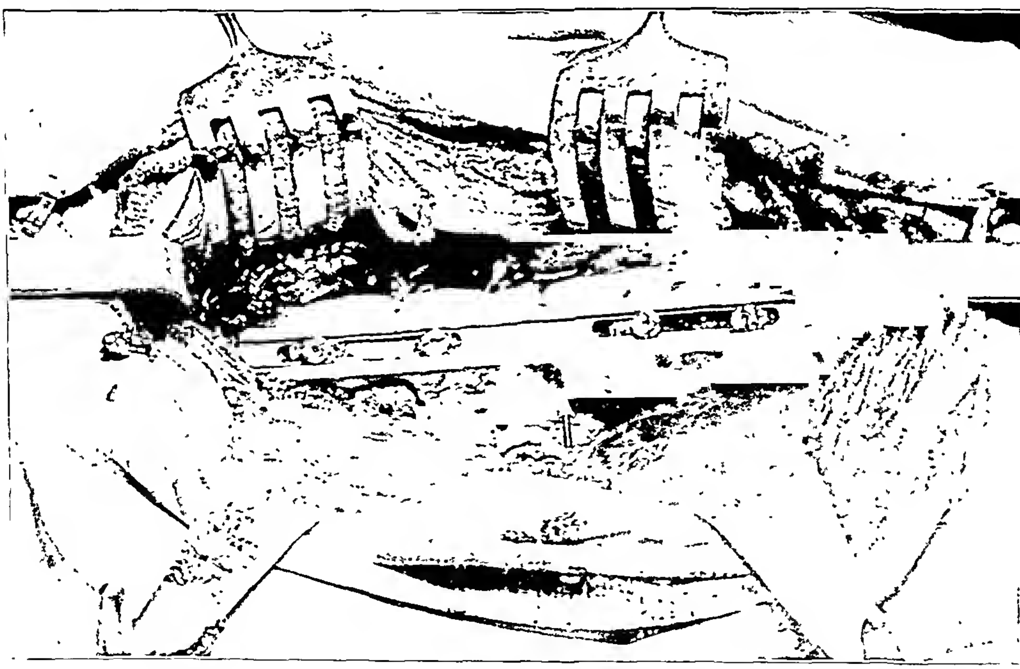

Fig. 5-C

Traction has been released, and fragment ends are in contact.

STABILITY TEST OF INTERNAL CONTACT SPLINT

The internal contact splint results in a dynamic accomplishment which can be understood more clearly if the following experimental procedure is carried out, thus permitting the surgeon a clearer appreciation of the principles involved:

1. A laboratory bone with an artificial fracture is prepared, and the splint is placed in position on the bone as in an operative procedure. The screws should be just loose enough on both sides so that the bone can be separated and united (Fig. 6).

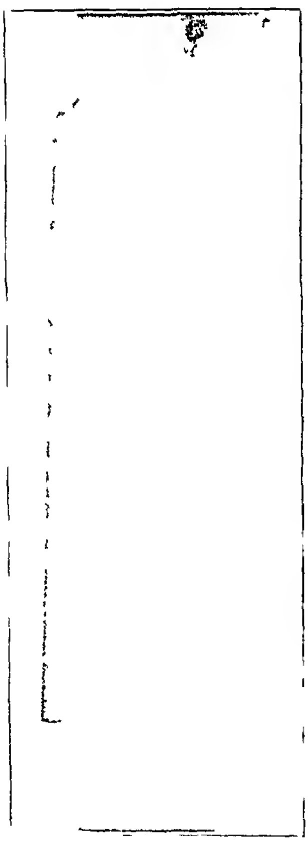

Fig. 5-D

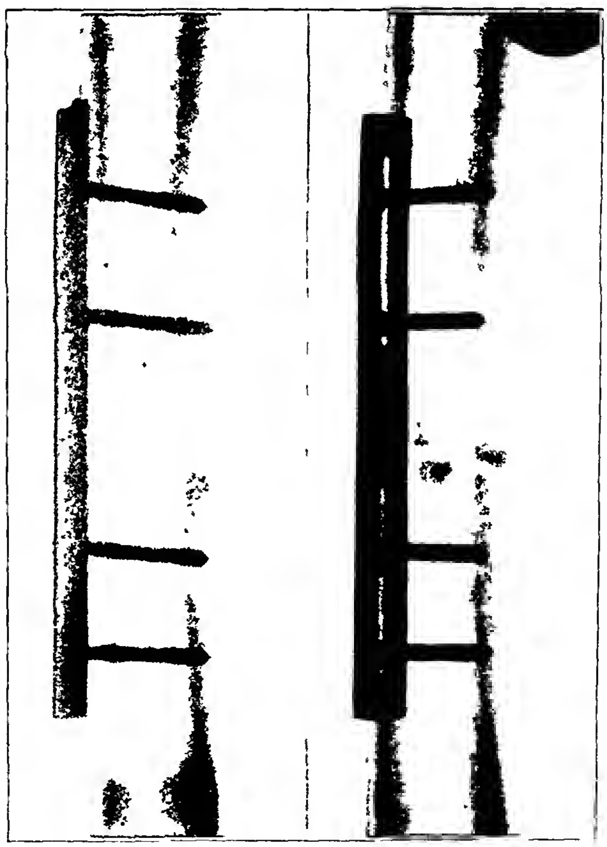

Fig. 5-E

Fig. 5-D: Nine weeks after reduction.
Fig. 5-E: Eleven weeks after reduction. Note changes in appearance of the fracture line.

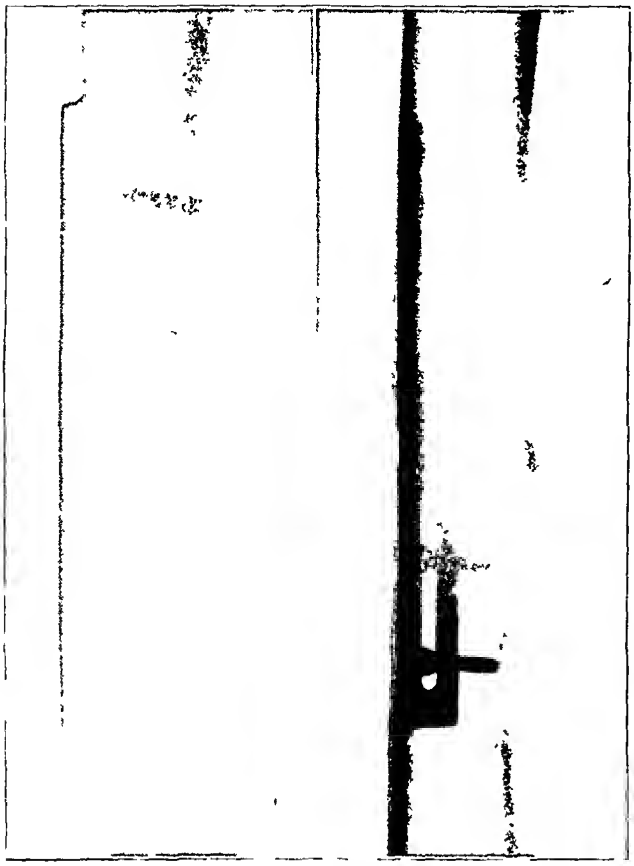

Fig. 5-F

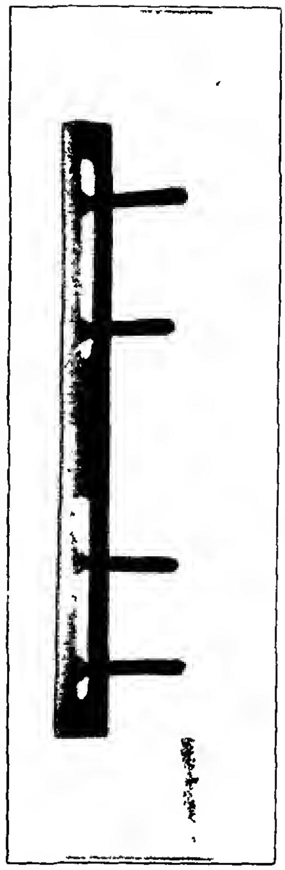

Fig. 5-G

Fig. 5-F: Sixteen weeks after operation. Progressive improvement has occurred at fracture line, but little periosteal activity.
Fig. 5-G: Forty-two weeks after operative reduction.

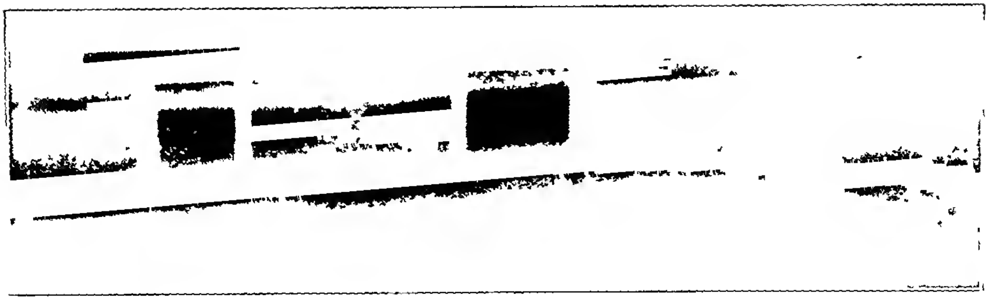

Fig. 5-H

Forty-two weeks after operation. Note union adjacent to splint, no atrophy of pressure, and union of the compact bone of the shaft,—the desired result.

2. One end of the specimen is held in the left hand and the opposite end is pressed against the chest, in order to simulate the longitudinal force exerted by the muscles in the clinical case. As the pressure is exerted, an attempt should be made to move the splint with the right hand, with the use of some type of instrument by which longitudinal pressure can be placed on the end of the splint. It will be found that the splint is actually in a locked position, due to the equilibrium of forces (Fig. 7). This assures stability, because the bone itself is bearing most of the strain. In immobilization with a rigid plate, the plate and screws must bear the greater part of the stress.

3. The second step of the procedure is repeated except that, before the fragment ends are pressed together, a thin piece of rigid metal is placed between them; then the longitudinal pressure is exerted. The intervening metal will be held in place by the pressure upon it. If the splint is checked, it will be found to be locked (Fig. 8). While the pressure is maintained, the intervening metal is pulled slowly; when the metal has been removed, the fragment ends will come into contact, and the splint again locks. This shows, even though the stability of the splint is secure, that the longitudinal migration of the ends is never prevented; and contact of the fragment ends during absorption of the devitalized bone is assured. Contact of the viable cortical bone is important, because its union is necessary for a successful recovery of the fracture. The low osteogenetic ability of compact bone

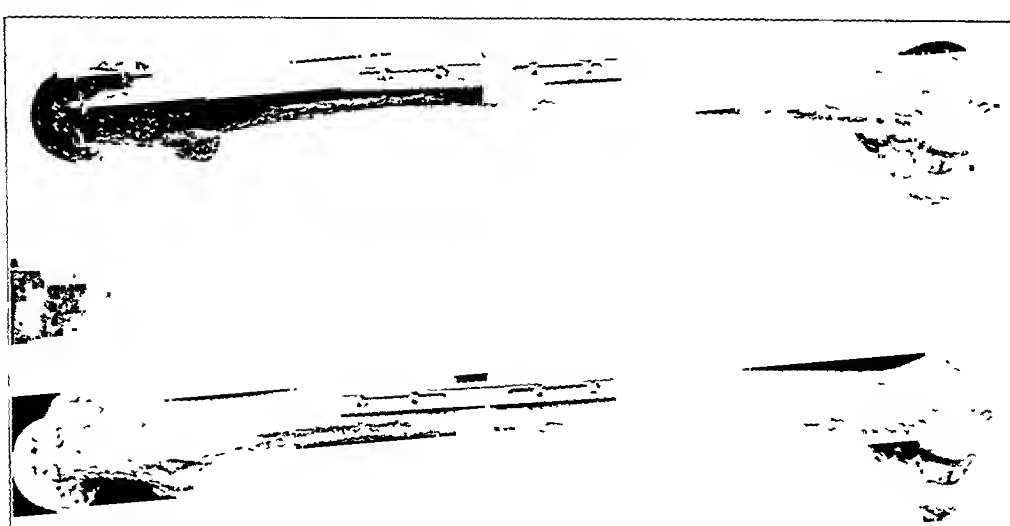

Fig. 6

Longitudinal muscle pull causes the fragments to glide into contact, because the screws are not tight.

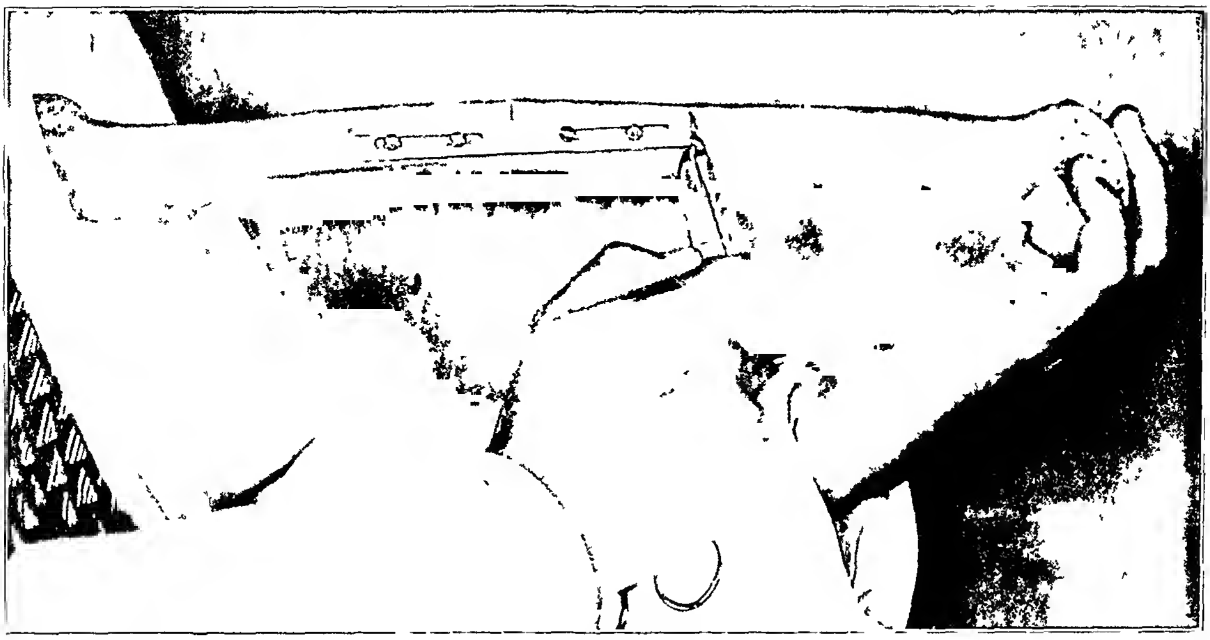

FIG. 7
As the longitudinal pull holds the fragment ends together, the splint locks, due to antagonistic geometric planes; thus the fracture is stable.

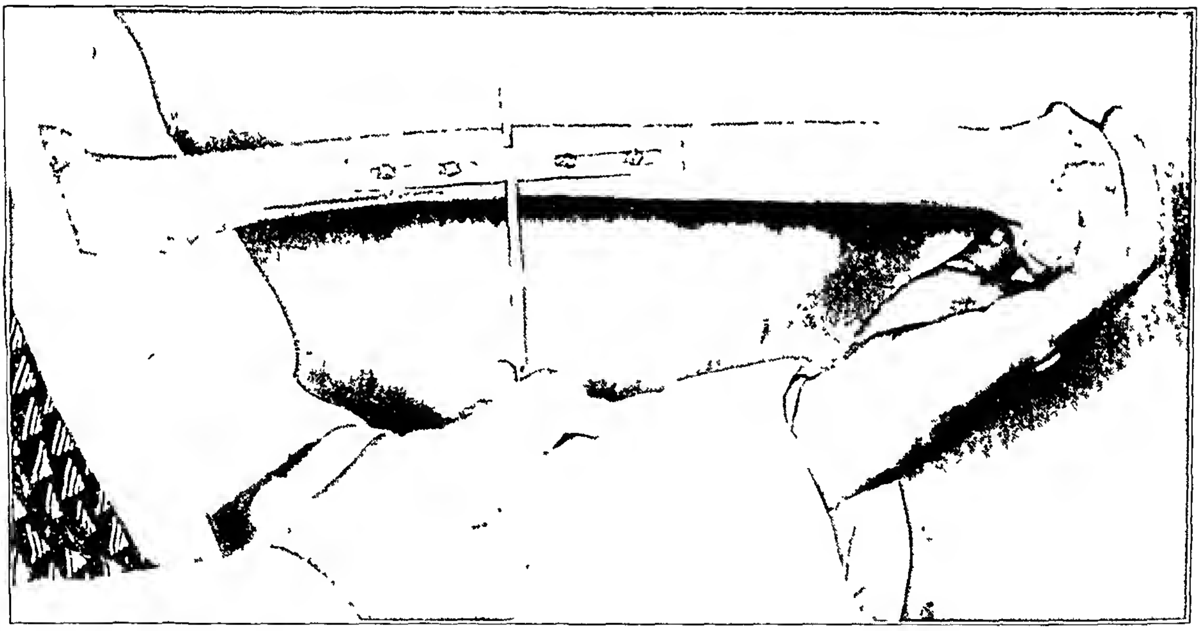

FIG. 8
An intervening strip is placed between the fragment ends; the longitudinal pull locks the splint and, in this case, the metal strip. If the longitudinal tension is continued and the metal strip is slowly pulled out, the bone ends immediately come into contact and the splint again locks. This assures continuous longitudinal mobility with constant locking of the splint.

requires close apposition of its viable elements for union. Irregularity of the fracture surfaces, when held together by the muscle pull, engage and control the rotary torsion.

SCREW PLACEMENT IN SPLINT APPLICATION

The application of the contact splint can be altered to accommodate the wishes of the operator. If there is any doubt in his mind that distraction may occur, he may place the first and fourth screws so as to touch the ends of the slots, and the second and third screws about one-quarter of an inch from the ends of the slots. Thus, the possible longitudinal migration of the fragments is only toward the fracture line, because its screws are not tight. This may be desirable in the femur, humerus, and tibia, as illustrated in the uppermost diagram of Figure 9.

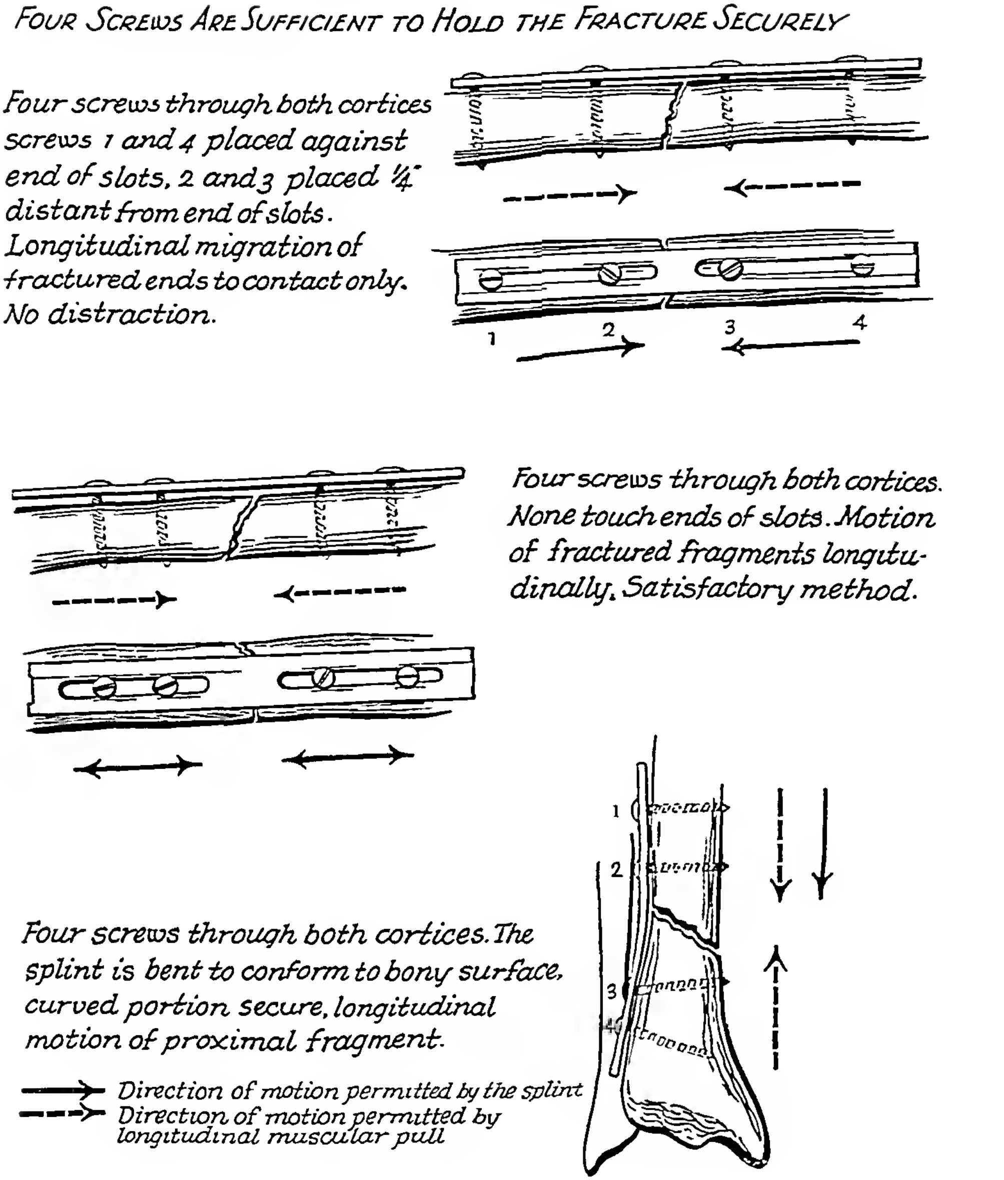

FIG. 9

The middle diagram shows the application of the splint, a longer longitudinal excursion being allowed than in the method described in the preceding paragraph. All four screws (not tight) are placed a slight distance from the ends of the slots. This method is quite secure and satisfactory for the femur, tibia, and humerus, and particularly for the forearm. When the radius and ulna are splinted, a splint is placed on each end; in the application of the second splint, if traction is desired for reduction, the pull can be applied with the assurance that the fragments first splinted will simply glide apart and then return to the corrected position, supported by the splint when traction ceases. This feature is very helpful in increasing the ease of reduction and the application of splints to the radius and ulna.

The diagram at the bottom of Figure 9 illustrates the bending of the splint to conform with the curved surface of the bone. The curved portion is more stable if it is fixed firmly by placing the screws securely, permitting the gliding motion to occur in the area of the straight portion of the splint. The third and fourth screws are secure; the first and second screws are not tightened; and the fragments glide together for contact.

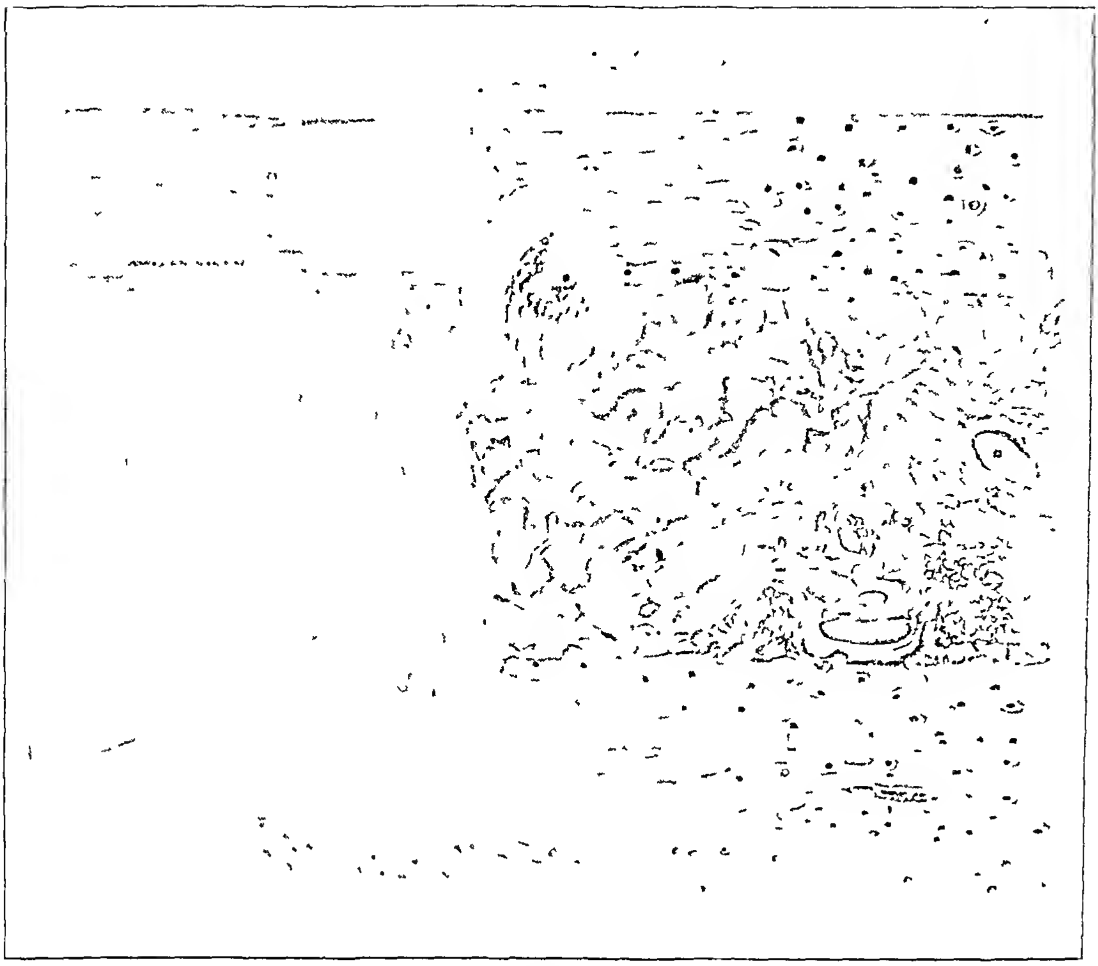

Fig. 10

Composite diagram of complete serial sections of fracture site, showing the areas of devitalization.

The important and necessary feature in the application of the contact splint is that it must allow longitudinal gliding of one or both fragments to assure constant contact.

To test the mobility permitted by the splint after application, anatomical traction must be applied before forceful sliding of the splint. The reason for this is that, when the bone fragments engage, due to the longitudinal muscle pull, the splint locks in position and, even though mobile, it will not move until the locking forces have been released.

Another method to test longitudinal mobility is to place a blade between the ends of the fragments, separate them slightly, and withdraw the blade; the fragments will then be approximated.

Experimental Study of Fracture Sites

BY WILLIAM H. AINSWORTH, M.D., AND NORMAN E. WRIGHT, M.D., GALVESTON

The experimental healing of fractures has been studied and recorded many times, with emphasis upon the histological, biochemical, physiological, and clinical features. All of these studies indicate clearly that bone, a living connective tissue, possesses certain distinct characteristics which should aid in the clinical care of fractures. In this series of experiments, the microscopic or histological features of fractures were studied, the femora of large dogs being used as the bone of choice. These animals were divided into three groups of about ten dogs each. In the first group, a simple fracture of the femur was produced in a standardized manner in the anaesthetized animal; the dogs were sacrificed on the second, fifth, seventh, fifteenth, and twenty-first days. The second group of animals were sub-

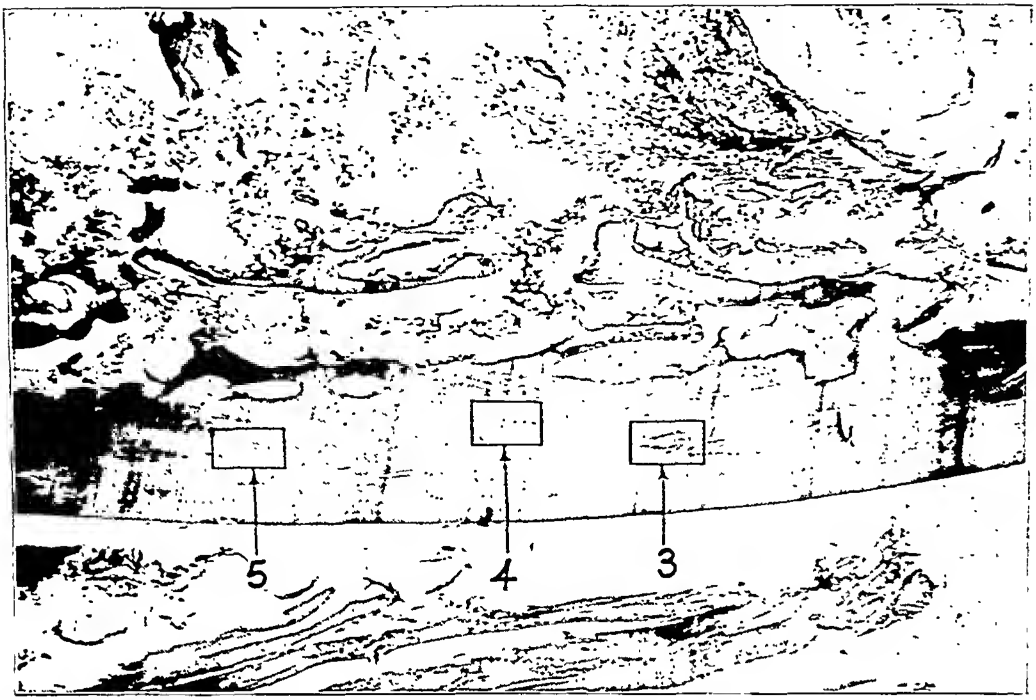

Fig. 11

Low-power study (× 40) of fracture site, to demonstrate areas from which higher magnifications were made.

Fig. 12

Photomicrograph (×160) of cortex near fracture site, showing lacunae which have no cellular content. Haversian canals also demonstrate the devitalization. (Section corresponds to *3* in Fig. 11.)

jected to the same type of fracture, but immediately afterward the fracture site was opened and the two fragments were simply exposed to the air; reduction was accomplished; and the wound was closed without any attempt at fixation or immobilization. In the third group, after fracture and exposure of the fracture site, the ends of the fragments were traumatized directly by ten blows of insufficient force to cause shattering or splintering of the cortex.

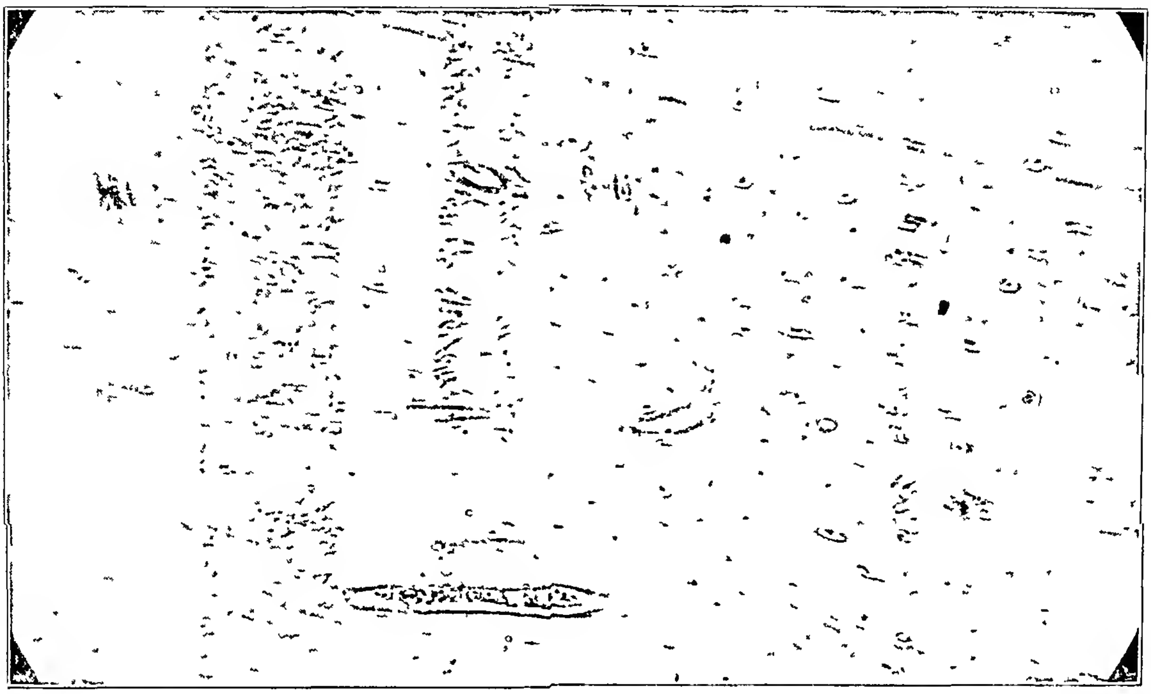

FIG. 13

Photomicrograph (×160) of cortex, showing devitalized cells interposed among living adult cells with normal Haversian systems. (Section corresponds to *4* in Fig. 11.)

FIG 14

Photomicrograph (×160) of cortex, showing normal living adult cells well beyond the fracture site, for comparison with Figs 12 and 13. Normal cytology is present (Section corresponds to *5* in Fig. 11.)

Each of the specimens removed was decalcified in hydrochloric acid and paraffin and mounted with serial sections through the fragment end, including the neighboring soft tissues.

The microscopic study of the tissue thus prepared presented a picture which has previously been reported by Ham and others, but a further description may be of interest. Attention was directed especially to the cortical portion; and, in the area adjacent to the fracture, the numerous lacunae which normally house the mature adult bone cells were found to be entirely devoid of cellular content. This observation has previously been re-

ported, but the extent of the devitalization bears more careful observation (Figs. 10 and 11). It was also found that the lining of the Haversian canals, consisting of a single layer of cells, called the endosteum, and a small capillary, had undergone marked destruction (Fig. 12). Thus it is felt that not only does the trauma necessary to a disruption of the cortex cause the death of the adult bone cells, but that a circulatory factor must be present as well.

Moving away from the fracture site, it was next noted that there was no definite line of demarcation between living and destroyed cells, but rather that the two zones blended together very gradually (Fig. 13). The first evidence of living tissue was found in the Haversian system nearest the marrow cavity, with a few normal adult bone cells in the adjacent area (Fig. 14). However, more destroyed cells were found farther away from the fracture site. The area of bone nearest the periphery of the cortex showed the most widespread devitalization. The highly cellular content of the marrow cavity did not show the destructive changes, except in that small portion at the fracture site; and here they were present not longer than forty-eight hours, because at this time the cellular changes of repair proliferation were beginning. The experimental fractures which were simple showed the least amount of cortical devitalization. The area varied somewhat, and an accurate measurement was not attempted because of the blending of the two zones. Those fractures which were compounded surgically, although sustaining no more trauma, showed a much wider zone of devitalization than the simple fractures. The most widespread area of destruction was found in the third group of animals, in which trauma had been applied directly to the fragments in compounded wounds.

Thus, in reality, when a fracture of any nature is reduced, devitalized tissue is placed against devitalized tissue; and the removal of this must be accomplished in the physiology of healing before solid bony union occurs[3]. Although the fate of this inert cortical bone was not followed for more than twenty-one days, it was felt that this tissue enters very actively into the healing process[1] by its local effect on the chemical composition and reaction of the hematoma and granulation tissue. The drop[4] in pH during the first two weeks, and the relatively high calcium and phosphatase content of the bone and hematoma are certainly a result of this mass of cortical bone which has lost its blood supply. As the circulation in the area is restored with the formation of granulation tissue and primary callus, the components mentioned are changed.

NOTE: The authors wish to express their thanks, for help received in this work, to the Departments of Anatomy, Pathology, and Medical Illustration of the University of Texas School of Medicine; to the Austenal Laboratories; and to Miss Estelle Greenwalt.

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DISCUSSION

DR. ARTHUR G. DAVIS, ERIE, PENNSYLVANIA: It is difficult to discuss a new instrument of this kind, because of the lack of criteria by which to judge it. We cannot look to the experimental laboratory to furnish enough evidence to evaluate the importance of the various factors which seem to be of significance in the process of osteogenesis at the fracture line. On the other hand, clinical evidence has been accumulated during the last thirty-five years, including use of the Lane plate, Sherman plate, and the refinement of metals to the final point of the Murray type of plating with Vitallium or some other inert metal.

During the last twelve or fifteen years, my own experience with the Murray type of plating has been highly satisfactory. As you all know, the Murray procedure aims at a hair-line apposition, the complete

elimination of all motion, and the elimination of shear strain at the line of fracture. The plate is put on vertically and a screw or two transfixes the fracture line at right angles to the direction of the plate, in order to eliminate shear strain and other oscillations.

Dr. Eggers's method at first glance appears to neglect these seemingly important factors. Dr. Eggers sent me his complete paper and a contact splint for experimentation. At first I could not understand how this plate could hope to eliminate the various kinds of stress encountered at the fracture line. In a transverse fracture, jamming the two fragments could eliminate shear strain; but in an oblique fracture, the impaction seemed impossible. Further study, however, showed that what actually happens with this adjustable plate mechanism is that, regardless of whether the fracture line is oblique, transverse, or irregular, the fragments become jammed the moment there is compression strain, as must inevitably be present as soon as the patient becomes conscious. Demonstrations on the skeletal specimen proved unconvincing. In order to visualize the manner in which the automatic adjustable mechanism works, one must assume the conscious patient and the fact that there is immediate musele eontraction; also the fact that all long bones are contained within a fascial compartment. The resultant of the total muscle contraction in kinetic energy, released in the fascial compartment containing the bone, must obviously be in the longitudinal axis, since most muscles contract parallel to the axis of the long bone. As the axial strain is imposed, the two main fragments slide toward each other as though mounted on a rack. As they become impacted, the horizontal elements of motion at the fracture line are also eliminated by the lateral and oblique thrust from one impaled fragment against the screw heads and plate transfixing the other main fragment. Thus it is clear that the contact splint has the potential of that highly desired state at the fracture line,—elimination of all abnormal motion. It also has the definite advantage of future adjustment or jamming in a case which has been badly done technically. If there is distraetion with the ordinary plate, this distraction persists. The contact splint does not permit such distraction to persist.

Dr. Eggers has described his operation in detail and has cited forty cases. He does not, however, cite the outcome in each case or state whether or not they are consecutive. Because of the success of the Murray technique when properly executed, I personally would be loath to abandon it for this new and as yet unproved method. However, I am definitely interested in following the evidence, because of the sound principles involved.

In this meeting we have had another corroborative piece of work, submitted by Dr. Phemister; this method is specifically for pseudarthrosis. Nevertheless, the same principles are exhibited in his work, and his very impressive results speak for themselves. If my interpretation of his method is correct, it is because of the compression strain, regardless of the graft, that calcification of the intervening fibrous tissue between the bone ends is actually obtained in his cases. We believe that this happens because the shear strain is converted into a compression strain, just as it is by doing a Shantz osteotomy for non-union of the hip. Evidence such as this tends to underline the importance of compression strain as a factor in both bone growth and fracture healing, since it is always present and, in the normal conscious human, forms part of the natural environment of the growing bone or of the bone undergoing repair. What, then, do we need by way of evidence to pass judgment on this method? Evidence is only as significant as the number of cases involved, plus the fate of each case in a consecutive series. If, for example, Dr. Eggers were to submit a consecutive series of one hundred cases, analyzed from the point of view of the patient's return to his former occupation, time of structural union, incidence of non-union, delayed union, and foreign-body reaction, we could then hope to evaluate this new and promising method. I am definitely interested in this method, and hope to keep in touch with Dr. Eggers' work as it proceeds.

Dr. Alfred O. Adams, Spokane, Washington: A few years ago, when we were doing limb-lengthening operations, we devised a means of determining accurately the amount of lengthening that had been obtained. A metal ruler, through which drill holes had been placed, was fastened to the lower extremity at the time the roentgenogram was taken. The same principle could be used in fractures, where fixation with a slotted plate is used, to determine how much absorption of the bone actually takes place.

This slotted plate could be marked as a ruler, in such a manner as to be recorded on the roentgenogram, and the distance between two screws, one in each fragment, could be measured soon after operation and at intervals until union occurred.

The position of the screws would remain the same in the bone, and any change in the distance between these two screws would be due to absorption of the ends of the fragments.

Dr. Harold E. Crowe, Los Angeles, California: We have all seen roentgenograms in which internal fixation with various kinds of metal held the fractured bone ends apart. Following the normal absorption of fractured bone ends, a gap must necessarily appear, and the internal fixation results in maintaining separation of the fragments. We have watched these metal plates bend in order that the bone ends, in their struggle to get together and produce union in spite of the interference of surgeons, might make contact and go on to union with important angulation. I am delighted that Dr. Eggers has had the courage to undertake this type

(*Continued on page 115*)

AN ANATOMICAL STUDY OF THE MECHANICS, PATHOLOGY, AND HEALING OF FRACTURE OF THE FEMORAL NECK

A Preliminary Report * †

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In search of a better understanding of fracture of the femoral neck, the anatomy and mechanics of the upper portion of the femur were subjected by the authors to a thorough study. Most questions relating to the problem, although apparently settled, were re-examined, with the result that we have revised our views of both the generally accepted crane theory of weight-bearing in the hip region and the important anatomical factors and healing mechanism in fracture of the femoral neck. Both the mechanics and the physiology of the femoral neck depend upon a bony system within the neck, which has hitherto received little attention.

The investigation took the following course: After dissection of the upper portion of the shaft and of the neck and head of the femur in normal specimens, and after roentgenographic analysis, miscroscopic examination of each structure was carried out. As the next step, the mechanical implications of the findings were studied in living persons in different age groups, by means of roentgenograms.

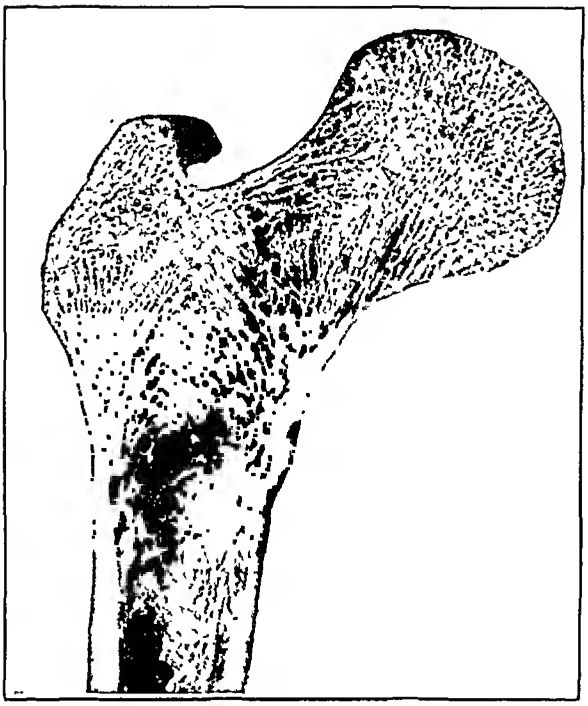
On the basis of the anatomical study, the pathology of fracture of the neck of the femur was re-examined, with particular reference to the discrepancy between the rapid healing of abduction fractures, with little or no treatment, and the slow healing or non-union of adduction fractures, regardless of treatment. Furthermore, the mode of trauma was studied. In abduction fractures the trauma is almost invariably a fall on or compression of the trochanteric region, while many adduction fractures, especially in the aged, are preceded by trauma which is seemingly insufficient to produce the injury. Thus in adduction fractures, some definite pathological changes in the femoral neck preceding the fracture had to be supposed, an assumption encountered both in the older and in the more recent literature [2, 13]. This assumption has been confirmed by the present study.

Finally, a new surgical method was developed and applied.

For the anatomical study, the bone marrow of the upper portion of the femoral shaft and of the neck was curetted out, with only light touches of the curette. After removal of the cortical shell of the anterior aspect of the femoral neck, the well-known trajectory system appears (Fig. 1). This consists of rather weak, spongy spicules, which yield easily to the curette. When, however, from one-eighth to one-quarter of the thickness of the neck close to the head has been removed, the curette strikes a bony structure almost as hard as cortical bone, roughly quadrangular in shape, and composed of a large number of closely packed lamellae (Fig. 2). This structure seems to spring from the inferior cortex and to spread from it, tending to extend partly toward the superior aspect of the cortex of the neck and partly toward the cartilaginous plate, where it terminates.

To have a better understanding of the extent of the structure, the lateral wall of the upper portion of the femoral shaft was removed, from the region of the greater trochanter to below the level of the lesser trochanter (Fig. 3-A). After the removal of the cortex, the spongy bone was curetted out until the instrument met a structure which felt like cortical

* This study was carried out under a grant of the Research Committee of the New York Medical College.
† Submitted for publication on January 27, 1947.



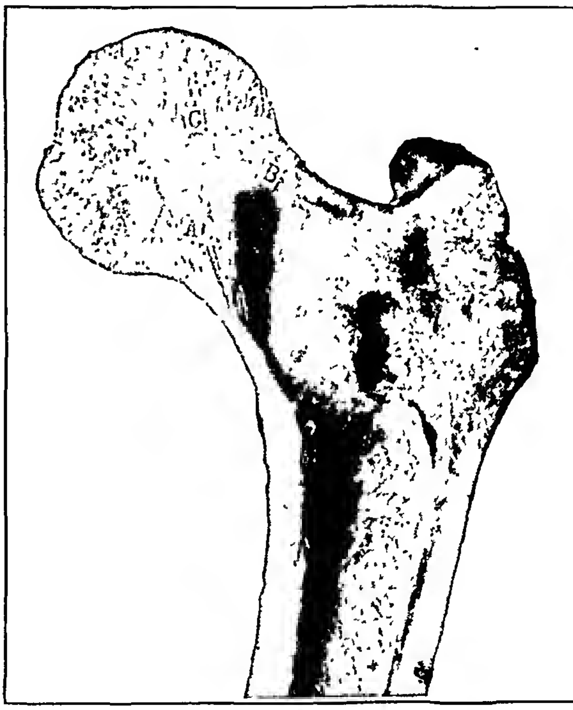


FIG. 1 FIG. 2

Fig. 1: Frontal section of the femoral neck and head in normal specimen from an older individual.
A: Trabeculae of the internal weight-bearing system may be seen entering the head.
Fig. 2: Frontal section of the femoral neck, after the spongy tissue has been curetted out.
A: Proximal end of the internal weight-bearing system with cartilaginous plate.
B: Supporting pillar for the internal weight-bearing system, arising from the upper cortical shell.
C: Cartilaginous plate.

bone. When this bony framework was followed toward the interior of the neck, it was found that it formed a bony septum, which apparently fused with the posterior cortex of the neck. It originated from the posterior and inferior aspects of the femoral shaft, two to four centimeters below the lesser trochanter. Toward the neck it turned posteriorly and apparently fused with the posterior aspect of the neck, near its center.

Beneath the postero-inferior wall of the neck, both the origin and the proximal termination of the bony system can be seen, with a cortical ridge connecting them (Fig. 4-A).

If, however, the whitish cortical covering of the ridge is chiseled off, which ought to be done carefully, the true extent of the system is disclosed (Fig. 4-B). Underneath the cortical layer of the connecting ridge, the same lamellar system is to be seen as throughout the course of the structure. It is then obvious that we are dealing with one *uninterrupted* lamellar system, running from below the lesser trochanter to the region of the cartilaginous plate, forming the proximal anchorage of the system. This largely independent bony framework is from ten to twelve centimeters long (Figs. 3-B, 5-A, and 5-B).

Even without removal of the cortical layer, in specimens representing a frontal section of the neck, the system may be recognized as clearly of different structure from the cortex, continuous in its course, and of laminar nature.

The system lines the inferior and posterior aspects of the neck. At the head it is strengthened by a strong pillar, also of laminar nature, springing from the superior aspect of the neck and joining the system just before it enters the head (Fig. 2,*B*). Throughout its course, the system as a whole and each of its individual laminae are enveloped by bone marrow. At and in the head it forms approximately the middle two-fourths in both the sagittal and frontal planes, while the anterior and posterior fourths are formed by bone marrow embedded in delicate cancellous bony framework (Fig. 6).

The relationship of the system to the cortical tube of the neck is of great importance. It can be seen, both in specimens and roentgenograms, that there is a reciprocal relationship between the strength of this structure and that of the cortical shell. The system is

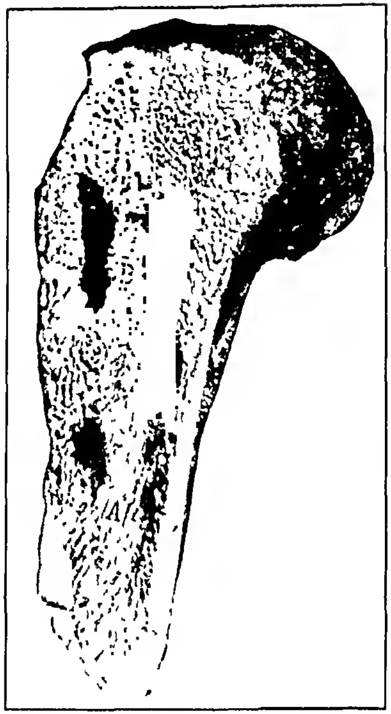


FIG. 3-A

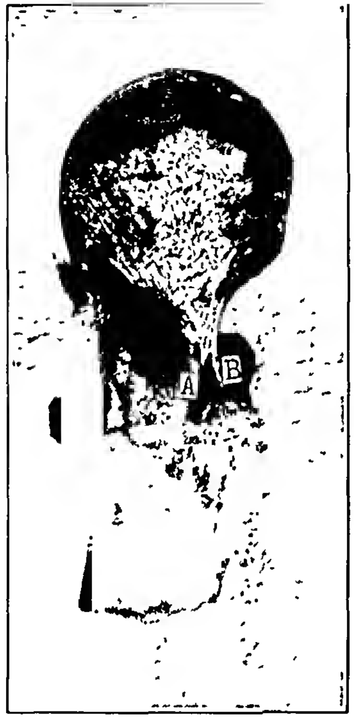


FIG. 3-B

FIG. 4-A

FIG. 4-B

Fig. 3-A: Normal specimen from proximal end of the femoral shaft, in the lateral aspect. Cortex has been removed.

A: Beginning of the internal weight-bearing system below the lesser trochanter.

B. Bony septum formed by internal weight-bearing system, entering the neck.

Fig. 3-B: Same specimen, seen from below after removal of the inferior aspect of the femoral shell.

A: Internal weight-bearing system.

B: Margin of posterior aspect of cortical shell, separated from internal weight-bearing system.

Fig. 4-A: Normal specimen of femoral neck, after removal of the inferior aspect of the cortex. *A:* Origin of the internal weight-bearing system.

B: Cortical layer covering the internal weight-bearing system. *C:* Termination of the internal weight-bearing system.

Fig. 4-B: After removal of the common cortical covering of the internal weight-bearing system and posterior aspect of the neck from same specimen.

A: Internal weight-bearing system. *B:* Posterior aspect of the femoral cortical shell, as clearly separated from the internal weight-bearing system.

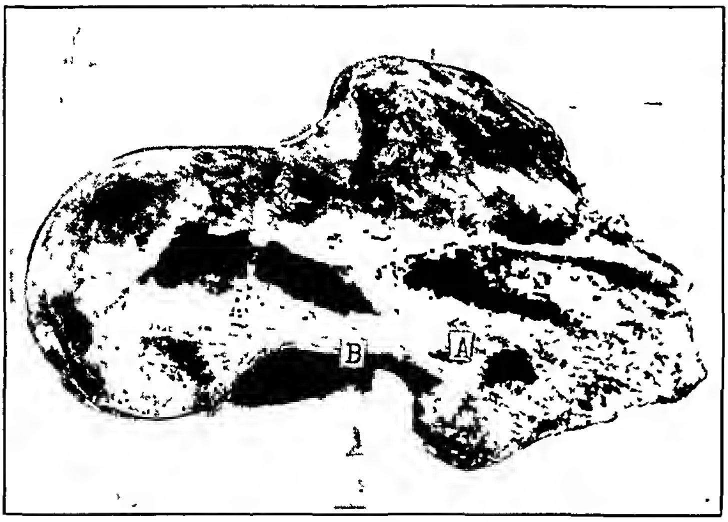


FIG. 5-A

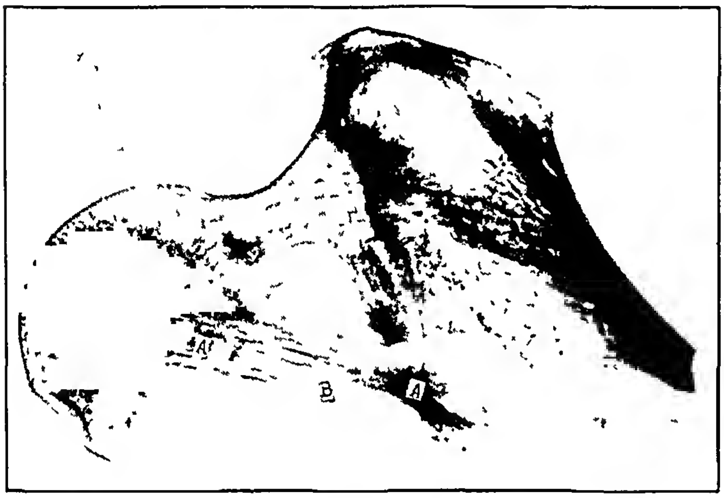


FIG. 5-B

FIG. 6

Fig. 5-A: Specimen from an older individual. Inferior aspect of the cortex has been removed.
A: Internal weight-bearing system, extending from below lesser trochanter to head. Note laminar character throughout its course.
B: Inferior aspect of cortical shell, clearly separated from laminar internal weight-bearing system.

Fig. 5-B: Roentgenogram of specimen shown in Fig. 5-A. *A:* Internal weight-bearing system. *B:* Cortex.

Fig. 6: Normal specimen after removal of parts of posterior aspect of cortex at the juncture of the head and the neck. Note the internal weight-bearing system as a massive cortex-like, whitish pillar, entering the head.

weakest at its point of apparent fusion with the neck, where the cortical bone reaches its greatest strength; while at the point where the system enters the head in fanlike fashion the cortical bone is the thinnest,—as a matter of fact, it is hair thin at the juncture of the head and the neck (Figs. 2 and 7-A). The significance of this arrangement in the mechanics of weight-bearing and in the pathology of fractures will be discussed later in this study.

After middle age the system starts to undergo slow resorption, beginning at its distal portion. At the same time, the cortical layer at the site of the apparent fusion of the structure with the neck gradually becomes thinner. In older patients the proximal portion becomes more brittle, the spaces between the laminae larger, and the number of laminae smaller (Fig. 7-B). In still older patients, around the ninth decade, the laminae at the distal portion of the neck appear to the naked eye as hardly larger collectively than one of the normal cancellous laminae. The bony structure, representing the cartilaginous plate of adolescence, gradually disintegrates and ceases to be the proximal point of anchorage of the system. After the dissolution of this structure, the laminar system continues directly to the articular cartilage of the head.

Although the distal portion becomes partly resorbed, the system is maintained throughout life. We have never failed to find it, even in the hips of patients close to one hundred years of age.

FIG. 7-A

FIG. 7-B

Fig. 7-A: Anteroposterior roentgenogram of the entire internal weight-bearing system, from below the lesser trochanter, in a younger individual. The laminae are closely packed as they enter the head.

Fig. 7-B: Roentgenogram of the internal weight-bearing system in an older individual. Laminae entering the head are widely spaced and loosely packed; individual laminae are clearly seen. Site of cartilaginous plate is in a state of dissolution.

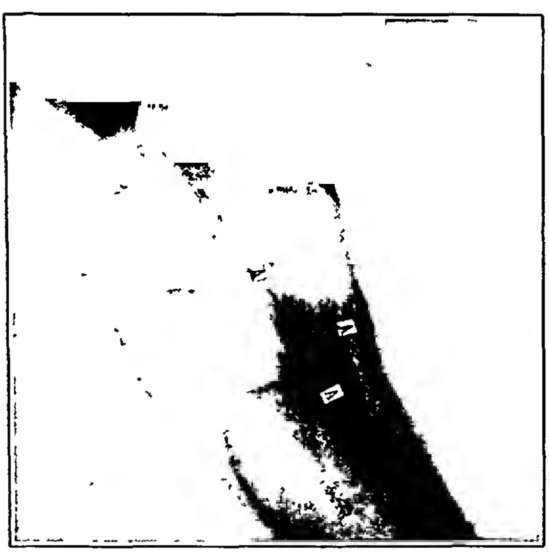


FIG. 8

FIG. 9

Fig. 8: Oblique roentgenographic view of the femoral neck.

A: Internal weight-bearing system is represented as a triangular shadow, running from the lesser trochanter into the head. This form of the internal weight-bearing system is not uncommon.

Fig. 9: Lateral roentgenographic view of the internal weight-bearing system.

A: Internal weight-bearing system skirting the lesser trochanter.

B: Site of apparent fusion between internal weight-bearing system and posterior aspect of neck

On the roentgenogram, the proximal portion is seen best on the anteroposterior view, the distal portion on the oblique and lateral views. The oblique and lateral views show the structure as a bony ridge or septum between the greater and lesser trochanters. Roentgenograms clearly show that the structure originates below the lesser trochanter, which it skirts from one to two centimeters anteriorly in its course toward its apparent fusion with

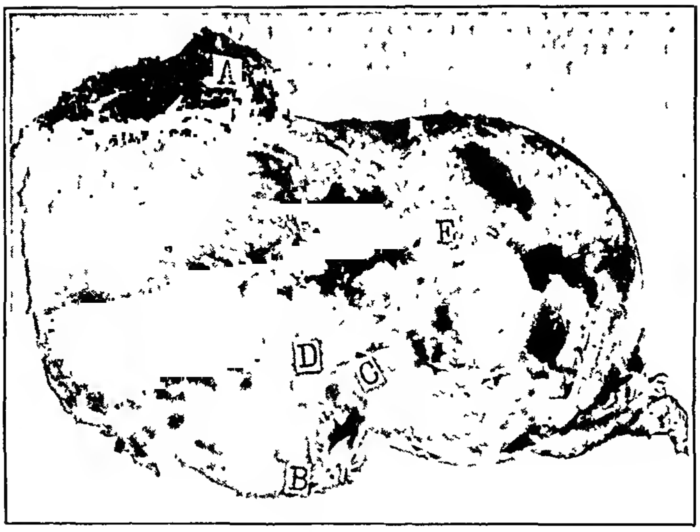


FIG. 10

FIG. 10

Specimen of neck and head of normal femur in an individual, eighty-four years old. Inferior aspect of the cortical shell has been removed. Internal weight-bearing system is preserved in almost its entire course.
A: Greater trochanter.
B: Lesser trochanter.
C: Posterior cortical shell separated from internal weight-bearing system.
D: Distal portion of internal weight-bearing system, of dark reddish color.
E: Proximal portion of internal weight-bearing system, of whitish color.

the neck (Figs. 8 and 9). In advanced age the roentgenograms show that the system is composed of laminae throughout its course; furthermore, the proximal laminae gradually become more and more separated, less numerous, and more loosely packed (Fig. 7-B). Another phenomenon may be observed in old age. Although the entire distal portion of the system is normally of reddish color, from the site of its apparent fusion onward to its termination, in the aged the reddish color turns whitish-yellow without transition from one color into the other (Fig. 10).

The microscopic examination, to be reported in detail in a forthcoming study, shows that the system consists of a large number of strong, spongy laminae with wide marrow spaces between them. It is endowed with a large number of bone cells and is lined with

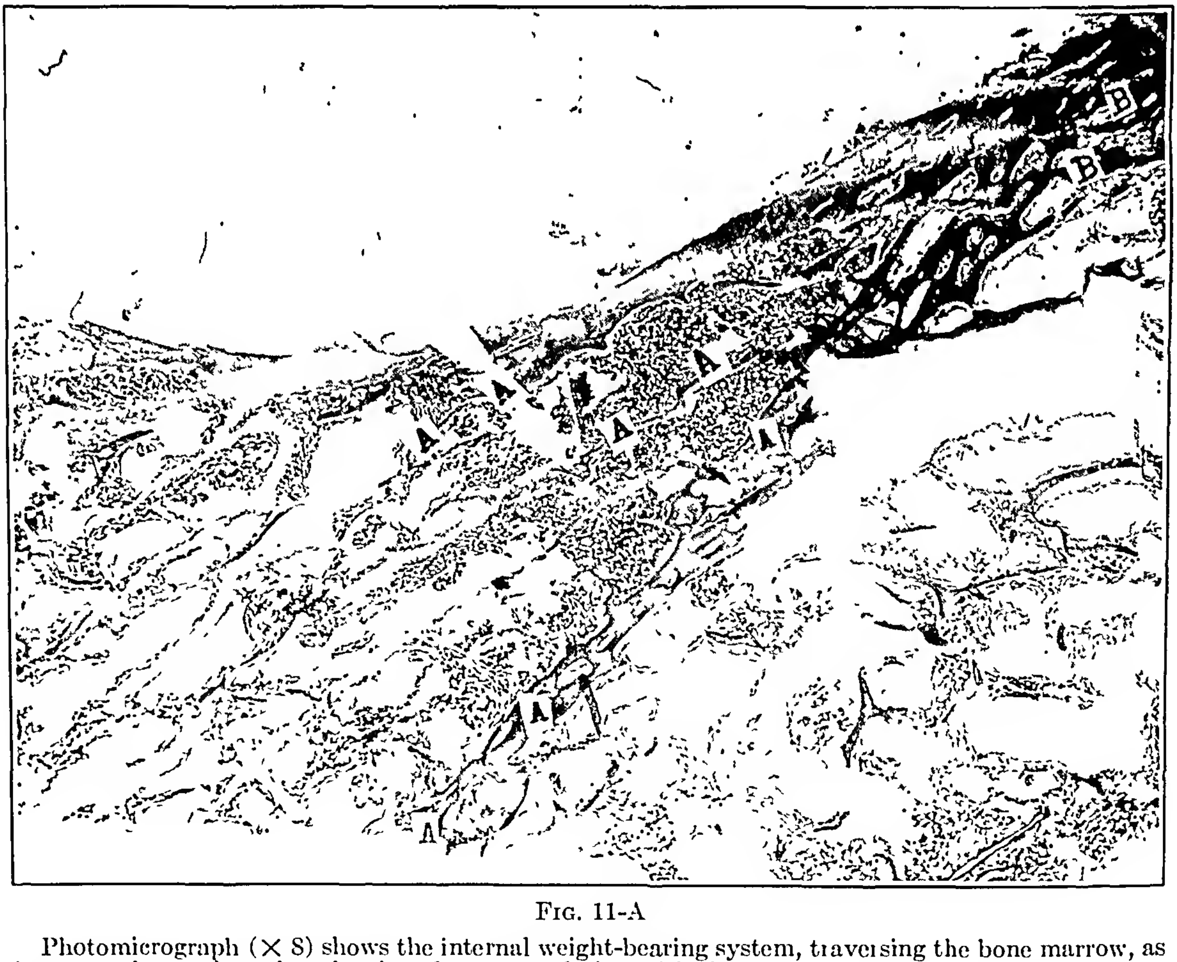


FIG. 11-A

Photomicrograph (× 8) shows the internal weight-bearing system, traversing the bone marrow, as it approaches and reaches the site of apparent fusion with the cortex. Note rich laminar character.
A: Internal weight-bearing system traversing bone marrow.
B: Site of fusion, — the weakest spot in the course of the internal weight-bearing system.

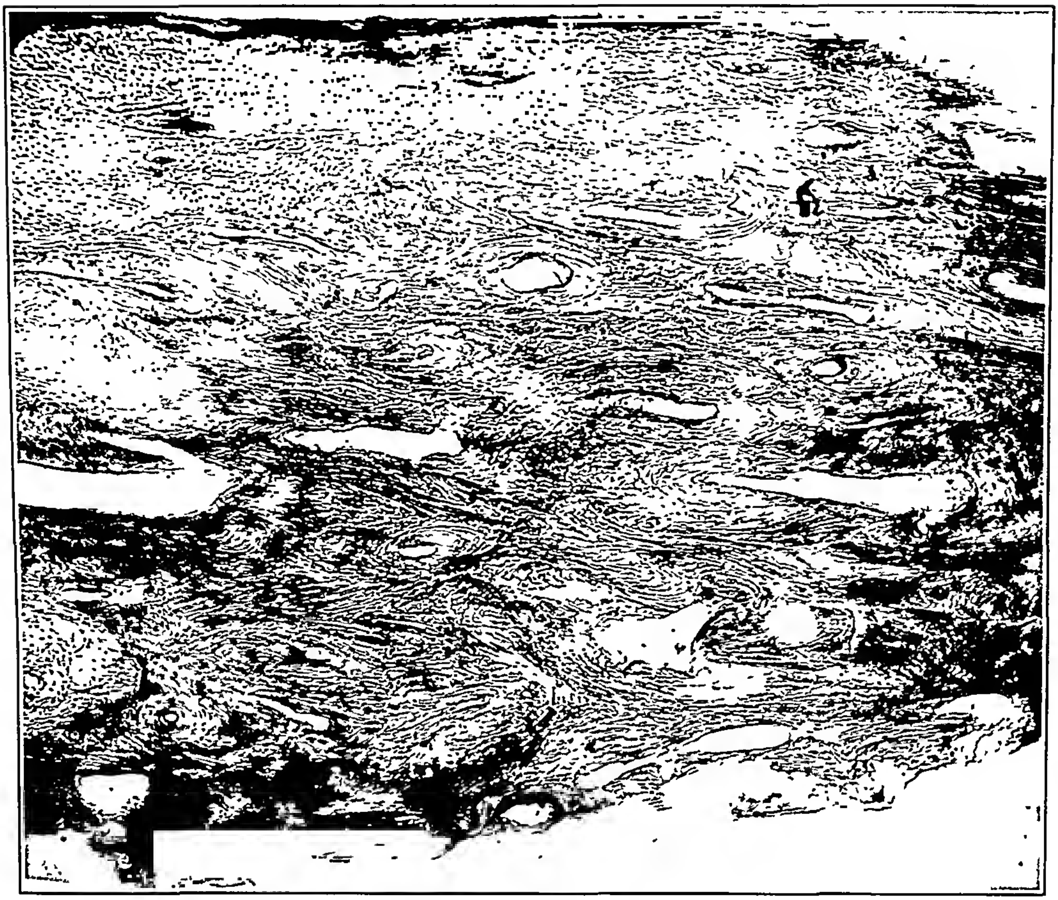


FIG. 11-B

Photomicrograph (× 100) taken from Fig. 11-A at *B*. Note the large number of cells, marrow spaces, and the endosteal lining.

highly cellular endosteum (Figs. 11-A to 11-E, inclusive). Histologically, it is similar to the spongy laminae of the iliac bone.

Reviewing the literature concerning the inner structure of the femoral neck, the authors found references to parts of the distal portion of the system under discussion. In 1844, Rodet described a cortical plate at the lesser trochanter and called it "*lame sous-trochantinienne*". Merkel called it "*Schenkelsporn*" or "*calcar femorale*"; Bigelow, "the true neck of the femur". Krause and Dixon refer to it as "*Lamina femoralis interna*". Dixon followed the lamina from the lesser trochanter up to its merger with the femoral neck. All authors agree that the lamina disappears completely after middle age, although Bigelow believed he had seen traces of it in some specimens in old age. No histological examinations have been reported. The femoral spur, the significance of which none of the authors could disclose, is part of the structure under discussion. Its complete resorption in old age is normally only apparent, not actual, as only its cortical covering disappears, and to the naked eye it does not stand out among the great number of laminae at the lesser trochanter. The roentgenogram and curettage reveal its presence throughout life.

The significance of the bony system in the interior of the femoral neck is threefold: (1) It is intimately connected with weight-bearing; (2) it is the chief source of bone repair; and (3) its transformation and partial resorption in old age comprise the main pathological factor preceding fracture of the neck of the femur, especially in the aged.

The mechanical implications of the system will be reported in detail in a separate study. Roentgenographically, it can be demonstrated that the structure is the *internal*

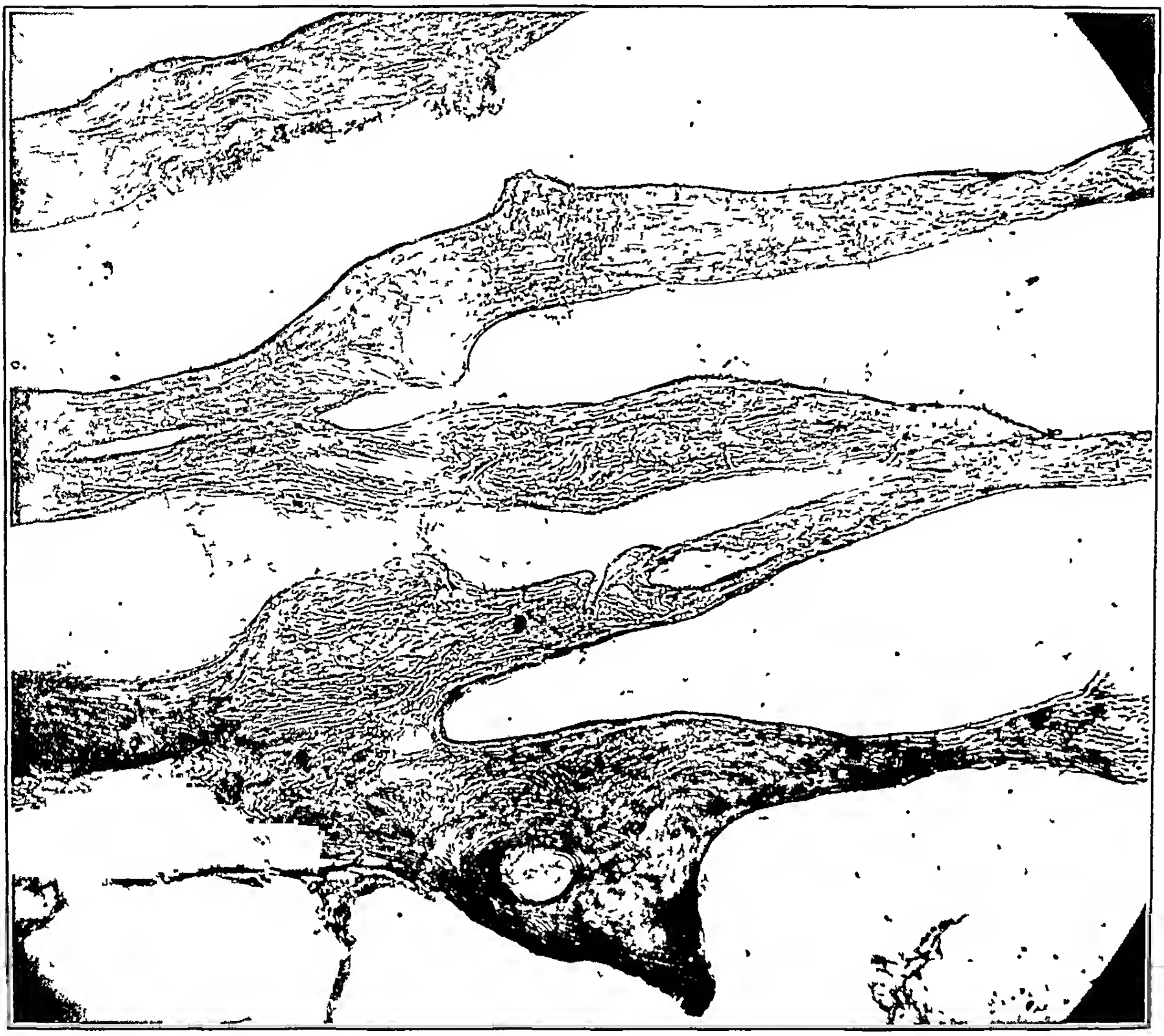


FIG. 11-C

Fig. 11-C: Photomicrograph (× 100), taken from Fig. 11-A at *B*, shows internal weight-bearing system after it leaves the site of apparent fusion and spreads out toward the head. A large number of individual laminae, which had been separated from one another and later connected by means of interlacing laminae, may be seen. The spaces between the individual laminae were originally filled with bone marrow, washed out during preparation. Note the slender laminae as compared with the large interspaces, the large number of bone cells, and the endosteal lining.

Fig. 11-D: Part of one of the laminae (× 600). Note the longitudinal arrangement of rows. The endosteal lining at one place indents the lamina in a baylike fashion.

Fig. 11-E: Individual lamina "sandwiched" between two wide layers of bone marrow, offering abundant nourishment for the normal lamina and taking care of its union after injury. Note the large number of cells on the laminar surface, and also the uninterrupted endosteal lining of the lamina (× 100).

weight-bearing system of the neck of the femur, forming an angle of from 3 to 8 degrees with the perpendicular during weight-bearing in youth and throughout middle age.

Walkhoff, in an excellent roentgenographic study, taking a stand against the crane theory of Meyer and Culmann, called attention to the heavy, spongy trajectories originating at the cortical shell of the neck and ending at the joint cartilage. He called them "*Trajektorien der aufrechten Haltung*" (trajectories of the erect position), and regarded them as spongy laminae which increased in strength as a result of weight-bearing. Although he failed to inquire into the anatomical nature of his roentgenographic findings, he proved his point to a great extent. He showed that the trajectories at the proximal end of the neck were completely missing in the primates and quadrupeds, and were poorly represented in the Neanderthal and Spy men. Walkhoff also found that, after the healing of fractures of the neck of the femur, only the dense trajectories running into the head were reformed, while the others failed to rebuild. His trajectories of the erect position are represented by the proximal terminus of the system under discussion. Walkhoff's con-

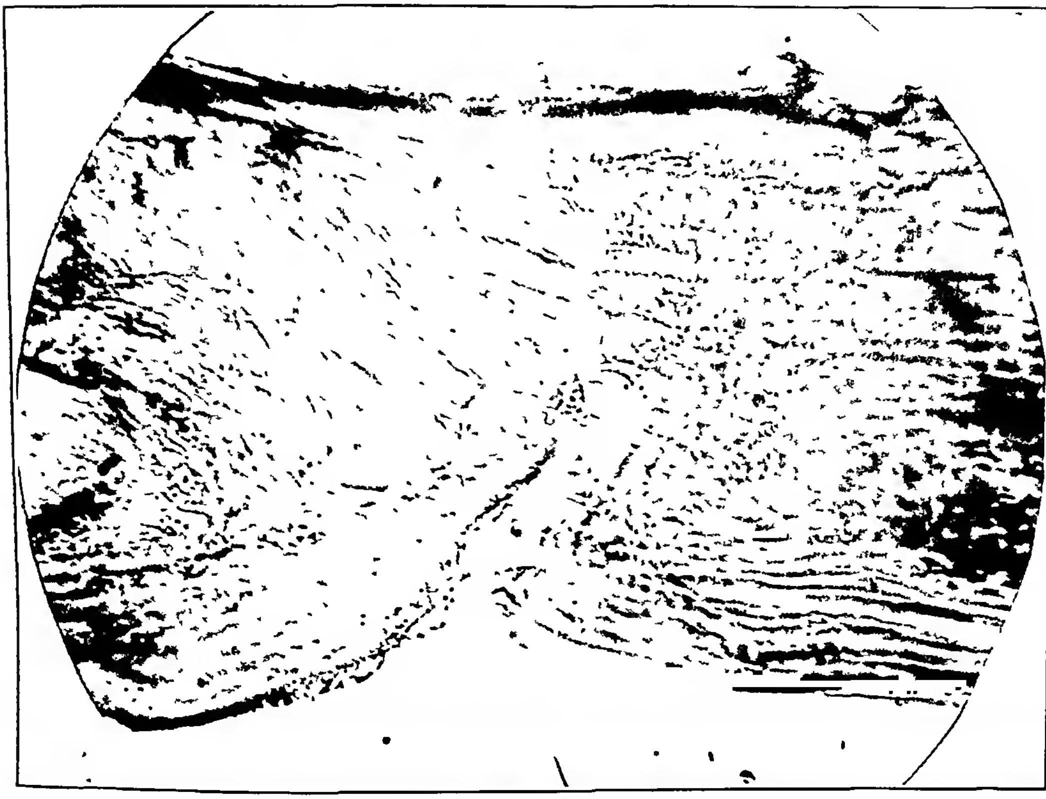


Fig 11-D

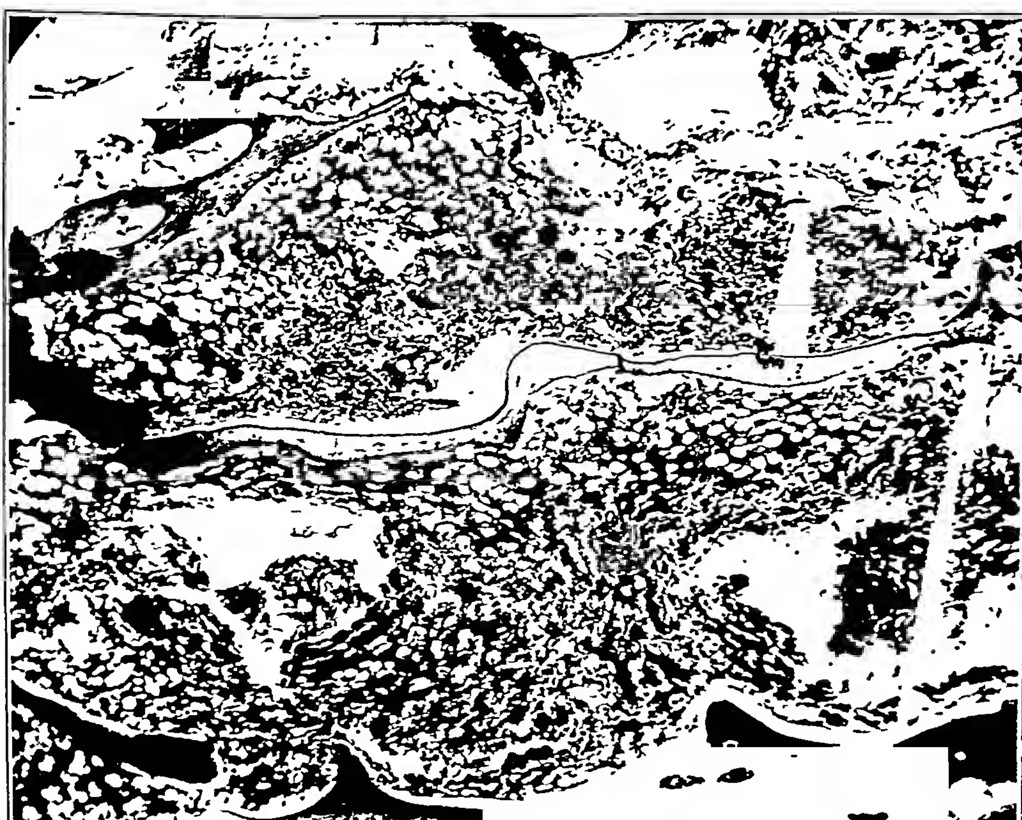


Fig. 11-E

FIG. 12

FIG. 13

Fig. 12: Anteroposterior roentgenogram after successful shelf operation for congenital dislocation of the hip. (*Courtesy of Dr. Leo Mayer.*)

A: Internal weight-bearing system below the shelf increased in strength and shifted to the vertical plane.

Fig. 13: Lateral view of femoral neck of eight-year-old boy. Cyst replaces the spongy structure of the upper shaft and neck. The internal weight-bearing system is preserved in its entire course. (*Courtesy of Dr. Leo Mayer.*)

ception is correct according to our analysis (to be reported later), in which we resorted to the roentgenographic method of investigation of weight-bearing at the hip.

In pathological conditions, when the mode of weight-bearing changes, the internal weight-bearing system always shifts to the line of weight-bearing. In subluxations of the hip and after shelf operations, for example, the system is greatly strengthened and shifted to the vertical plane (Fig. 12).

In congenital dislocations, without a rigid plane of weight-bearing, the system is reduced to a few laminae; in cases of ankylosis in which the weight is distributed all over the head of the femur, the system is scattered throughout the entire head.

Concerning the crane theory of the hip, Koch remarked: "It will be seen that the trabeculae lie exactly in the paths of the maximum tensile and compressive stresses . . .". The authors doubt that any tensile stresses are present around the hip joint. The system under discussion is a purely compression system, and the authors have not observed any other trajectories serving weight-bearing and the changes thereof. In addition, there is an important physiological fact, hardly compatible with the presence of tensile stresses: The epiphysis of the femur would normally show slipping in every human being, if tensile stresses amounting to two or three hundred pounds arose at its site, as the epiphyseal line could hardly withstand such an enormous displacing force.

Thus the bony structure under discussion appears to be the internal weight-bearing system of the neck of the femur, a compression system and apparently the only spongy structure in the femoral neck serving weight-bearing. Its physiological value is apparent in the case of cysts in which the entire spongy structure of the femoral neck has become resorbed, except that the internal weight-bearing system remains preserved, as an entity, as does the cortical shell (Fig. 13).

The role of the internal weight-bearing system in bone repair can best be observed during the healing of fractures of the neck of the femur. Being a spongy laminar structure,

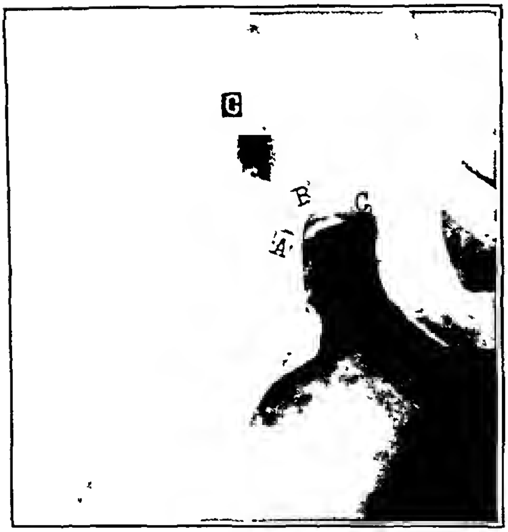


Fig. 14

Fig. 15

Fig. 14: Lateral roentgenogram of an abduction fracture of the femoral neck, four weeks after injury.
A. Fracture line of the internal weight-bearing system at the end of the proximal cone.
B: Fracture line of the cortical shell, along the neck.
C: Fracture line of the cortical shell at the juncture of the head and the neck.

Fig. 15: Anteroposterior view of abduction fracture of the femoral neck. Note that the laminae are bent only, and not broken, as in a greenstick fracture.

extremely rich in bone and endosteal cells, beset with marrow spaces—the individual laminae, as it were, "sandwiched" between layers of bone marrow—it biologically represents the bony structure which shows the safest and speediest medium of bone repair among all bony tissues (Figs. 11-A to 11-E, inclusive). The experiments of Matti, Ghormley and Stuck, Dick, and others with grafts—taken in some cases from the iliac bone and in other cases from the lateral aspect of the femur (the region crossed by the internal weight-bearing system)—proved the unique value of this type of tissue in bone repair.*

The experiments of Bergmann with bird bones, which possess air holes in place of bone marrow, show the paramount importance of the endosteum. After the experimental fracture of the long bones of birds, the examination of the healed fracture showed that the bony cavity, until then empty, was filled with endosteum, developed from the few endosteal cells apparently indispensable in bone repair.

All this implies that in fractures of the femoral neck, if the internal weight-bearing system is strong and healthy and its fragments are in close apposition, speedy and safe healing may be expected; while, if the internal weight-bearing system has undergone pathological changes, healing of the fracture with normal function is at least improbable. The pathological changes in fractures of the femoral neck seem to confirm this supposition.

For the present study, eight specimens with fracture of the neck of the femur were available,—seven of them with ununited fracture of the femoral neck, and one with a healed fracture. Before examination of the pathological specimens, roentgenographic analysis of a large number of cases of fracture of the neck of the femur was carried out with special reference to the internal weight-bearing system.

In the *abduction* fractures, it was noted that fracture of the internal weight-bearing system and of the cortical shell usually occurs at their weakest points. The internal weight-bearing system breaks around the middle of the neck; and the cortical shell, at the cervicocapital juncture. Therefore, a fracture plane results which is wedge-shaped at the distal

* At the proximal end of the humerus the roentgenogram reveals a system resembling that under discussion. The presence of such a system may account for the speedy and safe healing of fractures in this region, frequently encountered even in the aged.

portion, where the separation of the internal weight-bearing system takes place; from there it runs parallel with the cortical bone, vertically broken at the point where the neck joins the head (Fig. 14). In many instances of abduction fracture, one may see the internal weight-bearing system in the state of a greenstick fracture (Fig. 15). This may account for the rapid healing without treatment. The reason for the lack of displacement in such fractures, even if the internal weight-bearing system has been completely separated, is the possibility of impaction by dint of the great number of laminae, derived from the system, being pushed and hooked into one another. The fast healing of such fractures results from the biological nature of the internal weight-

Fig. 16

Fig.16

Specimen of a healed adduction fracture of the femoral neck. Inferior cortical shell has been removed.

A: Posterior wall of the neck.

B: Anterior wall of the neck.

C: Internal weight-bearing system, in marked proliferation and callus formation.

D: Callus, originating from the internal weight-bearing system, bridging posterior and anterior walls.

E: Callus, originating from the internal weight-bearing system, filling fracture line between head and neck.

F: Remnants of capsule, engulfed by callus.

Fig. 17-A

Fig. 17-B

Fig. 17-A: Specimen of an ununited adduction fracture of the femoral neck, six weeks after injury. No distinct internal weight-bearing system can be seen.

A: Posterior wall of the neck is greatly increased in width as a result of possible conversion of the internal weight-bearing system into cortical bone.

B: Newly formed laminae, originating from distal fragment, closing off the distal fragment from the proximal one.

Fig. 17-B: Anteroposterior roentgenogram of same specimen.

A: Cortical shell is greatly increased in width. No separate internal weight-bearing system can be seen.

B: Lamina sealing off the distal fragment.

bearing system, as previously pointed out. Also in *adduction* fractures, the healing of the fracture is fast and uneventful, if the fragments of the internal weight-bearing system are in good apposition and the structure is of normal composition.

The roentgenographic signs, in fracture of a bone with a normal internal weight-bearing system, are the following: The laminae are numerous; they are densely packed; the proximal fragment of the internal weight-bearing system is long; its end is blunt and not pointed. Naturally, the proximal fragment of the structure has to be brought into contact with the distal fragment of that system. Distraction of the fragments of the internal weight-bearing system may bring about non-union.

In fractures of bones with a normal internal weight-bearing system, the site of the separation of the structure usually does not coincide with that of the cortical shell. Almost all fractures belonging to this group are caused either by a fall on the region of the greater trochanter, or by the pelvis being caught in a vise or similar mechanism. They are all crushing injuries and represent *compression* fractures of the femoral neck.

FIG. 18

Anteroposterior view of ununited adduction fracture of the femoral neck.

A: Conelike proximal fragment consists of the terminal laminae of the internal weight-bearing system.

The fractures in which a normal internal weight-bearing system is present comprise all abduction and "intermedial" fractures (those with marked recurvation at the site of fracture) and many adduction fractures, to employ the sound classification of Per Linton.

The specimen at the authors' disposal with a healed fracture showed that the new-bone formation proceeded from the internal weight-bearing system. The system increased in volume and extent, crossed the cavity of the neck, grew into the cortical shell, and, forming what appeared to be cortical bone, penetrated into the head (Fig. 16). A portion of the capsule was engulfed by the new bone. The remnants of the capsule proved histologically to consist of fibrous tissue, leukocytes, and a large number of histiocytes.

The specimens with non-union had all had adduction fractures. Only insignificant remnants of the internal weight-bearing system could be found in them, even in the two recent specimens. Thorough study revealed that the resorption of the internal weight-bearing system was not a simple disappearance of the structure. From the site of its distal anchorage, below the region of the lesser trochanter, the entire distal portion of the internal weight-bearing system had been transformed into cortical bone. The posterior aspect of the cortex became twice or more its original thickness (Figs. 17-A and 17-B).

The separation takes place at the cervicocapital juncture, as is typical of this type of fracture of the femur; the separation line of the cortical shell and that of the internal weight-bearing system are in the same plane. The proximal fragment of the internal weight-bearing system is a conelike structure which still contains many laminae (Fig. 18).

Consideration was given the question of why the conversion of the internal weight-bearing system into cortical bone should affect only the distal portion of the system, and why the central portion should break atraumatically, as it were. The conversion of the spongy laminae into cortical bone takes its origin from the cortical shell. Wherever the internal weight-bearing system is closely apposed to the cortical shell, this conversion may be an easy process under certain pathological conditions preceding fracture (see Comment). The proximal portion of the internal weight-bearing system, however, branches off

from the cortical shell to enter the core of the head in fanlike shape. After this deviatio it does not abut cortical bone, but is surrounded on all sides by bone marrow.

Apparently at the point where the cortical shell ceases to support the internal weigh bearing system, a slow resorption takes place and the pathological separation occurs. Th process may be preceded by the conversion of the bone marrow, surrounding the capit and subcapital laminae, into fatty marrow, while the rest of the system remains embedde in red marrow, as mentioned before (Fig. 10). Nowhere do spongy trajectories or lamina form the continuation of cortical bone; only the inner layers of cortical bone are forme everywhere by spongy tissue. This could hardly be the case with the internal weight bearing system. After the marrow deteriorates, the proximal end of the internal weight bearing system loses its blood supply and separates, because it has become the continuatio of a system subject to a different mode of nutrition. Although the spongy structures dra their blood supply mainly from the bone marrow itself, the cortical shell is supplied chiefl by arteries of the capsule and of the periosteum. After the bone marrow has disintegrated the distal end of the internal weight-bearing system, converted into cortical bone, is sup plied with blood, much as occurs in the rest of the cortical shell of the neck. However, n adequate source of blood is present to supply the proximal spongy laminae; and, after th reduction in their number and strength or after change in the character of the marrow sur rounding them, separation occurs.

Thickening of the posterior cortical shell is one of the main roentgenographic sign preceding and accompanying adduction fractures of the aged. Other signs of equal signifi cance are the following: The proximal fragment of the internal weight-bearing syster contains only a few more or less distinct laminae; the spaces between the laminae are large and the proximal fragment ends in a short cone, the end of which is a sharp point. Th site of separation of the internal weight-bearing system and that of the cortical shell coin cide; both are to be found at the capitocervical juncture (Fig. 18). This is in contrast t the findings in so-called abduction fractures.

The trauma preceding the adduction fracture may be a fall on the region of the greate trochanter, but this is not necessarily the case. Frequently, especially in old people, suc normal functions as sitting down, getting up, turning in bed, or simple slipping of the fee are the "injuries" preceding the fracture. Frequently one gains the impression that th fracture of the cortical shell occurred after the patient's fall, and that the patient fell at th instant when the proximal portion of the internal weight-bearing system had separated from its distal portion. The adduction fractures showing the signs enumerated, especially in the aged, appear to be closely related to pathological fractures. In reality, they represent a definite form of subcapital separation. Thus as regards etiology, there are two distinct types of fractures of the neck of the femur:

1. *Compression fractures* of the femoral neck, comprising all cases showing a healthy internal weight-bearing system, and consisting of abduction, intermedial, and also of adduction fractures.

2. *Subcapital separations* with subsequent fracture of the cortical shell, comprising only adduction fractures.

The prognosis and treatment of the two types are fundamentally different. The compression fractures may heal in from four to eight weeks, if the proximal and distal fragments of the internal weight-bearing system are in apposition and if care is taken in their fixation. A plaster bandage or Russell traction may be used, but with Russell traction no more than four pounds should be applied, lest the fragments should separate. Nailing will hasten union and render the fixation safe, but the relatively high number of cases with necrosis and deformity after nailing is probably due to the procedure.

The subcapital separations, in order to unite, need such treatment as is capable of either replacement of the internal weight-bearing system or of its stimulation by biological, mechanical, or perhaps chemical means.

Mechanical means are employed in the procedures of nailing or drilling. Both seem to be able to act on the remnants of the internal weight-bearing system in such a manner that the cells revive and multiply, forming new bone. In addition, in several specimens it was found that new-bone production started from the remnants of the internal weight-bearing system,—not enough to unite the fragments, but sufficient to cover the distal fragment with a layer of new bone. This newly formed lamina seals off the distal fragment from the proximal fragment, excluding any possibility of spontaneous union (Figs. 17-A and 17-B). In this respect the drilling, with its holes, and the nailing, with its large channel breaking through the separating lamina between the fragments, may induce the spongy laminae of the internal weight-bearing system to grow into the proximal fragment. It should be emphasized, however, that no method has even a fair chance of producing union which disregards the fact that only the conelike end of the proximal fragment is capable of adequate new-bone formation, as it contains the terminal portion of the laminar internal weight-bearing system. Consequently, the proximal fragment has to be brought into contact with the remnants of the internal weight-bearing system in the distal fragment, or, if the system be missing and replaced, with the spongy surface of the graft. This contact is the main sign of good reduction.

Naturally an attempt has been made to replace surgically the internal weight-bearing system in fractures of the neck of the femur. The problem was to find and insert into the neck a bony structure sufficiently hard to maintain reduction, but at the same time consisting of bone, at least similar to that to be replaced, and capable of adequate new-bone formation in a relatively short time. As the authors' studies had shown that union of the cortical shell in fractures of the neck of the femur proceeds mainly from the internal weight-bearing system (Fig. 16), the former structure could not be relied upon as the means of bony union in the absence of a rich source of bone repair within its confines.

The spongy structures of iliac bone are best suited for such a procedure but, being too soft, they would hardly maintain reduction. Therefore, the cortex of the femur just distal to the greater trochanter was used, a structure employed by Matti in his experiments to prove the superiority of spongy bone for grafting purposes. After long experimentation, from fifteen to twenty minute holes were drilled into the graft before it was removed. This allowed the spongy surface of the graft to grow through the drill holes, and the host surface to use the same channels to engulf the graft, thus uniting with a speed of which only the spongy laminae are capable. The graft is now inserted frontally, with its broad periosteal surface facing the anterior wall of the neck.

The graft was named the perforated or sieve graft. As it was applied closely underneath the cortical shell, resting, as it were, on the inferior surface of the neck, in analogy of the onlay and inlay grafts, it was called a "sublay graft". Hence its name is "*perforated* (or sieve) *sublay graft*".

The technique and the results of the method will be reported soon.

COMMENT

The fast healing of abduction fractures cannot be explained solely on the basis of the angle between the fragments and the vertical plane, as claimed by Pauwels. Such fragments do not become displaced, apart from the angle, for the following reasons: (1) because the internal weight-bearing system is similar to the bone in a greenstick fracture; (2) because no tensile stresses are present at the hip region; and (3) because the internal weight-bearing system heals so fast that by the time the patient starts weight-bearing, bone repair in the interior of the neck might have proceeded almost to complete union.

It also appears probable that the reason some fractures remain in the state of abduction fractures is that the internal weight-bearing system does not permit further displacement. Not the angle of separation, but the state of the internal weight-bearing system, is the chief factor. The problem of abduction fractures is biological rather than mechanical.

One of the purposes of this study has been to arrive at a biological explanation of abduction fractures.

By experimental testing, Kolodny found that, to produce a compression fracture of the femoral neck, an average of about 375 pounds are required; while Dixon found that to bring about a vertical break, from 1,800 to 2,500 pounds are required. This corresponds to a fall of 150 pounds of body weight from a height of twenty-eight feet. Therefore, it is conceivable that the neck of the femur may break when one falls on the side, crushing the femoral neck; but it is hardly conceivable that adduction fractures, especially of the aged, would occur as a result of the injury alone, when one takes into consideration the amount of impact required to produce it.

As to the cause of the transformation of the internal weight-bearing system into cortical bone in the distal part of the system, the work of David Greig might be referred to. According to this author: "Restrict the blood supply and bone undergoes consolidation, increased density, osteosclerosis". One is tempted to assume that arteriosclerosis of the marrow vessels, decreasing the blood supply of the structures depending upon them, may lead to both the deterioration of the laminar system and the deposition of a new cortical layer on the marrow surface of the cortical shell.

SUMMARY

Dissection and roentgenographic analysis of the upper portion of the shaft and neck of the femur revealed the presence of a highly independent laminar, bony system, from ten to twelve centimeters long, which begins from two to four centimeters below the lesser trochanter and ends in fanlike fashion at the cartilaginous plate of the head. This proved to be the internal weight-bearing system of the proximal portion of the femur.

This system undergoes slow resorption in its distal portion after middle age, but never disappears; and on the roentgenogram it can be seen throughout life from its distal to its proximal end. Microscopically, it consists of a great number of laminae and bone cells, and a rich endosteal lining. It resembles the spongy laminae of the iliac bone,—hence the speed with which it is capable of new-bone formation.

Mechanically, the internal weight-bearing system is a compression system, and during weight-bearing it is to be found almost in the vertical plane. The presence of tensile stresses is doubtful.

Preceding adduction fractures, the internal weight-bearing system is resorbed and replaced by cortical bone in its entire distal portion. Its proximal end remains spongy, with laminar character. The separation occurs at the site where the spongy proximal portion begins and the distal cortical portion ends.

In abduction fractures, the internal weight-bearing system suffers only trauma, but otherwise it is healthy and strong. This explains the rapid healing of such fractures.

On the basis of the anatomy and pathology of the femoral neck, two types of fracture may be distinguished: (1) compression fractures, comprising the abduction, intermedial, and adduction fractures; and (2) subcapital separations, represented by most fractures of the aged. The prognosis of the compression fractures is good, if the fragments are kept in good apposition and fixation in plaster, in Russell traction, or by nailing.

For the treatment of the adduction fractures, a method with a perforated (sieve) sublay graft has been developed.

NOTE: The authors wish to express their gratitude to Dr. James W. Benjamin, Professor of Histology at the New York Medical College, for his interest and advice in the histological studies; to Dr. Frank J. Borrelli, Professor of Radiology at the New York Medical College, Flower and Fifth Avenue Hospital, who carried out the large number of roentgenographic examinations and developed methods best suited for the roentgenographic representation of the structures concerned; and to Mr. E. R. Hajjar, photographer of the New York Medical College.

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HOMOGRAFTS IN ORTHOPAEDIC SURGERY *

BY MYRON O. HENRY, M.D., MINNEAPOLIS, MINNESOTA

A fairly large group of children and adolescents need surgery for various orthopaedic conditions in which excessive amounts of bone are required for grafting. A vast quantity of suitable bone may be secured from the relatives of the patient. Good results may be expected from the use of homografts; the danger of shock is less, and there is less disfigurement of the patient.

Wade reported successful grafting of bone from another individual in an ununited fracture of a long bone nearly thirty-five years ago. Recently, homografting has been practised quite extensively in battle casualties, and the satisfactory results obtained seem to warrant its wider use. Albee, Armstrong, Meyerding, and others admitted the value of homografts long ago, but expressed preference for autogenous grafts. Time and experience have proved the superiority of the autogenous graft; but there are many instances, especially in children and adolescents, where enough autogenous bone cannot be secured. In children, the tibia is often too small, and sufficient bone cannot be removed without danger of injuring the epiphyseal plates. The quality or strength of the patient's bone (whether tibia or ilium) may be inadequate. The additional shock from the removal of the graft is always to be considered.

For these and other reasons, surgeons have searched for many years for substitutes for autogenous bone. Beef bone, ivory, and even cow horn have been used, but have gradually been discarded. Os purum, os novum, and boiled bone have been used successfully by Orell. Os purum has been used quite extensively in this country by Goff, who believes that it has a definite place in bone surgery and is a satisfactory material for grafting. His work shows that os purum seems to be tolerated by the host as well as autogenous bone, but at the present time there is little or no os purum available in this country. Inclan and others have used preserved bone in patients in whom the operative risk was high, when it was inadvisable to use autogenous bone because of the extreme difficulty of acquiring it, or when the osteogenic power of the bone which was available was poor.

* Read at the Annual Meeting of The American Orthopaedic Association, Hot Springs, Virginia, June 28, 1947.

FIG. 1-A

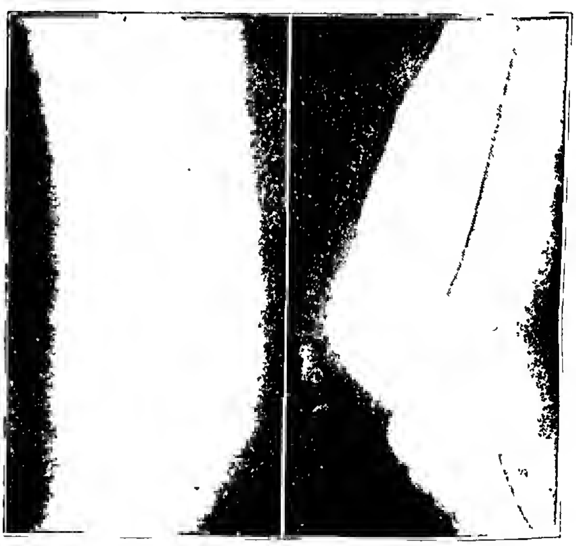

FIG. 1-B

Fig. 1-A: Case 1. The patient was a boy of seven years, with a preoperative diagnosis of giant-cell tumor of the femur. The cavity was curetted and filled with autogenous chip grafts from the tibia.
Fig. 1-B: Seven months after operation. The grafts are taking.

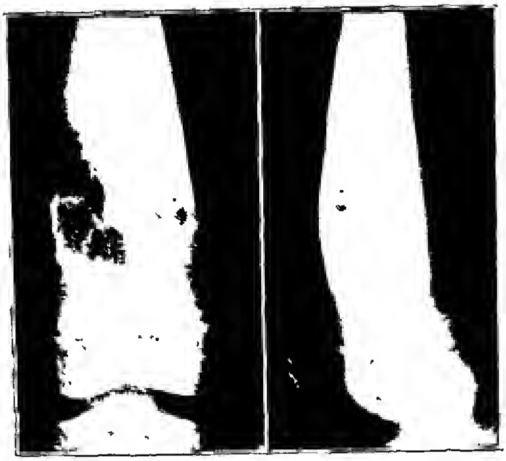

Fig. 1-C

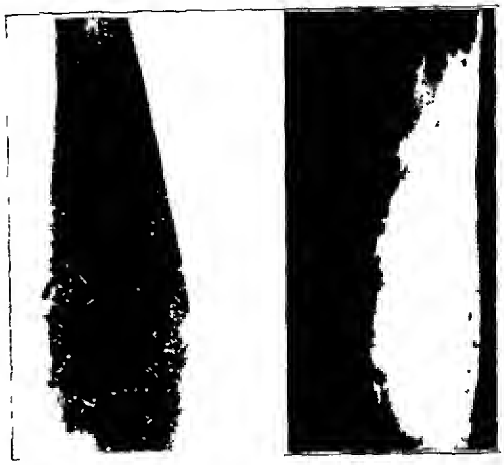

Fig. 1-D

Fig. 1-C: Twenty-one months after operation. Partial recurrence after the use of autogenous chip grafts.

Fig. 1-D: Two months after second operation. Cavity was curetted and filled with chip grafts from the father.

Fig. 1-E: Four months after second operation. Chip grafts from father are taking well.

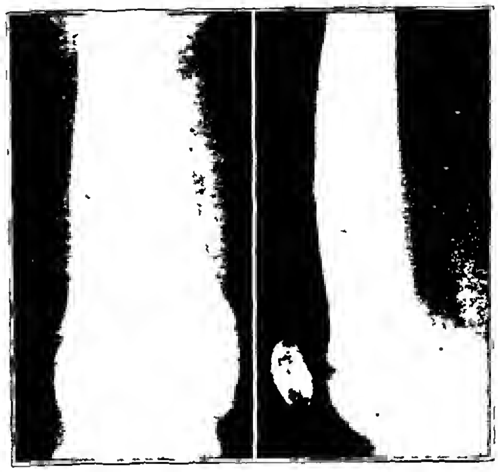

Fig. 1-E

World War II has stimulated interest in preserved bone grafts; and, at present, work is progressing in some clinics to establish banks of preserved bone. As soon as the danger of infection can be eliminated, the use of preserved grafts will undoubtedly find a place in orthopaedic surgery. Boiled grafts and autoclaved grafts have long been used when grafts became contaminated in the operating room, and good results have been reported.

Objections to the use of homografts have been made by some authors, who fear transmission of disease, incompatability of blood and Rh factor, or differences in sera. Boyd, Ghormley, and others who have used homografts more extensively find no need even for matching blood, because very little blood is transplanted with the bone. Because of these and other reasons, homografts may not have had the wide application they deserve. The objections to homografting do not seem to be supported by clinical evidence. Theoretically, the closer the relationship of the donor to the recipient, the better the chances of success.

In the accompanying examples of homografting, all of the grafts have been taken from male relatives of the patient and are syngenesioplastic grafts. The blood was matched in every case, but this seems unnecessary. Syngenesioplastic grafts are easily obtained in private practice from the father or brother, who is usually willing to donate bone from the tibia or ilium. Most brothers consider the contributions little more than blood transfusions. Syngenesioplastic chip grafts of cortical bone were used in each of the cases presented. More recently, H grafts and chip homografts of cancellous bone have been employed, and the results promise to be equally good.

In benign, destructive bone tumors in children, frequently enough bone cannot be obtained from the patient himself, especially if the tumor recurs and more bone is needed. The opposite tibia can be used, but further recurrence may suggest the need of telescoping the bone or of looking elsewhere for osteogenic material. In such cases, the father can donate the necessary bone (Figs. 1-A, 1-B, 1-C, 1-D, and 1-E).

In severe destruction by benign bone tumors, it may be technically impossible to excise the tumor thoroughly. If the tumor recurs, amputation or telescoping may be avoided by filling the new cavity with bone from a brother; and, should further extension

Fig. 2-A

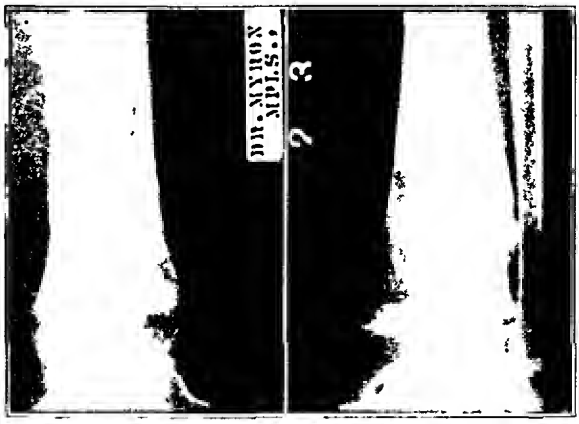

Fig. 2-B

Fig. 2-A: Case 2. The patient was a girl, eight years of age, with a clinical diagnosis of hemorrhagic cyst of the tibia. Note relationship to epiphyseal line.

Fig. 2-B: Five months after operation. Cavity was curetted and filled with autogenous chip grafts from opposite tibia.

Fig. 2-C

Fig. 2-D

Fig. 2-C: Ten months after operation. Partial recurrence took place following the use of autogenous chip grafts.

Fig. 2-D: Two months after second operation. Cavity was curetted and filled with chip grafts from patient's brother, aged seventeen.

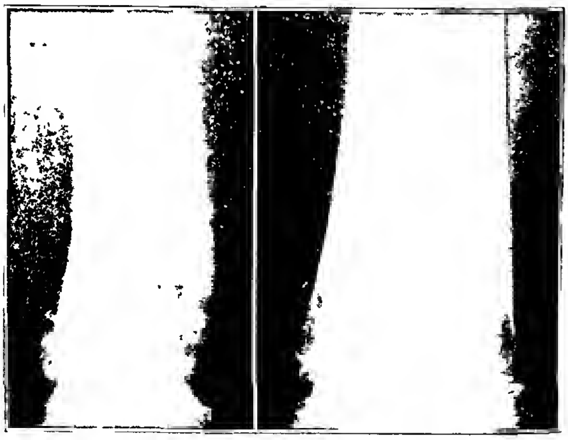

Fig. 2-E

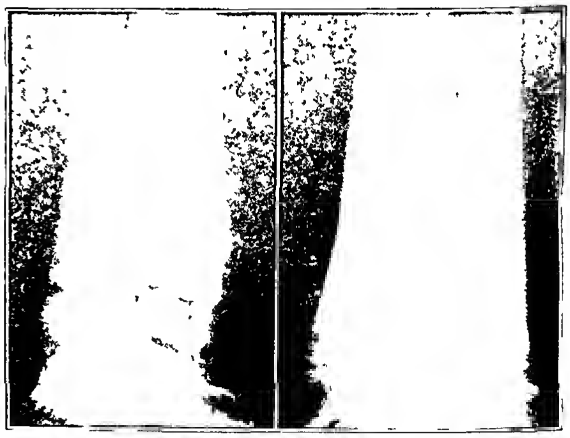

Fig. 2-F

Fig. 2-E: Four months after second operation. Grafts are taking. Note that growth is continuing.

Fig. 2-F: Shows beginning recurrence of tumor proximally, eleven months after homografts.

Fig. 2-G

Fig. 2-H

Fig. 2-G: Two weeks after third operation. Cavity was again curetted and filled with chip grafts from another brother, aged sixteen years.
Fig. 2-H: Two years after third operation.

Fig. 3-A

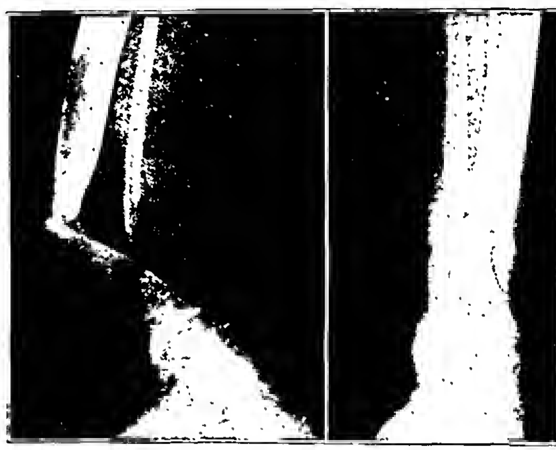

Fig. 3-B

Fig. 3-A: Case 3. A male infant, one month old, showed evidence of congenital pseudarthrosis of the tibia. Roentgenogram, taken at the age of seven months, shows subperiosteal fracture.
Fig. 3-B: Two years after spontaneous fracture had been treated by plaster-cast immobilization.

Fig. 3-C

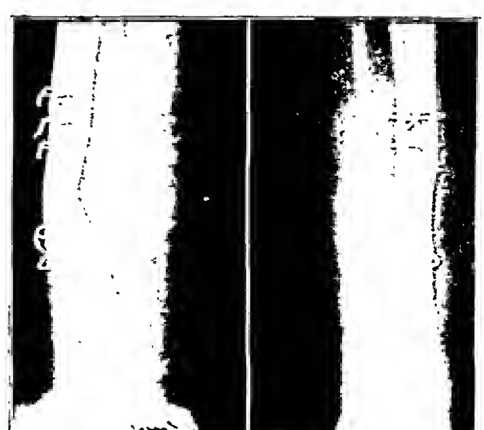

Fig. 3-D

Fig. 3-C: Dual grafts from father have been applied, by the method of Boyd.
Fig. 3-D: After six months, dual grafts are part of host. Fracture has healed.

Fig. 3-E

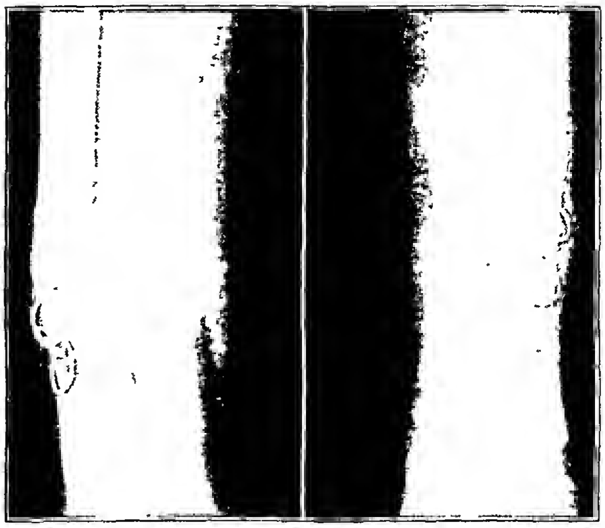

Fig. 3-F

Fig. 3-E: Refracture occurred eleven months later.
Fig. 3-F: Roentgenographic appearance nine months after refracture.

occur, bone growth and apparent cure may be possible by the use of grafts from a seconc brother (Figs. 2-A to 2-H, inclusive).

In pseudarthrosis of the tibia, Boyd reported that: "Autogenous grafts are preferred but in children it is difficult to secure sufficient bone for a good onlay graft, and impossibl to obtain enough for a dual graft". This is verified by the author's experience. Althoug dual grafts from the father may take well and may become a part of the host, such grafting will not prevent refracture in pseudarthrosis any better than autogenous grafting will; but grafting may be repeated at a later date, if necessary (Figs. 3-A to 3-F, inclusive).

In structural scoliosis, spondylolysis, and spondylolisthesis, especially in young girls, a psychological factor frequently affects treatment. Many of these young patients resent operative scars on legs or hips, and often, to avoid the scars, prevail upon their families tc abandon the operation. In such instances, the homograft solves the problem. Brothers and other male relatives are often proud to contribute bone. Although autogenous grafts are considered to be better, there is a definite place for homografts.

CONCLUSIONS

1. When a sufficient amount of bone, or bone of proper quality, cannot be easily and safely obtained from the patient, the surgeon should consider syngenesioplastic grafts or homografts.

2. The results with homografts—especially syngenesioplastic grafts—warrant wider use in certain conditions.

3. To date, there is no factual evidence to prove that homografting, in selected cases, is not a sound surgical procedure.

4. Greater experience with homografts may advance the art of orthopaedic surgery.

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DISCUSSION

Dr. Rufus H. Alldredge, New Orleans, Louisiana: Orthopaedic surgeons everywhere will be indebted to Dr. Henry for calling attention to such a valuable, and heretofore rarely used, method of bone-grafting. This is an important subject, and there is no doubt that much more will be heard about the use of homogenous bone in the near future.

Dr. Henry has used homogenous bone chips in most of his patients, because of the nature of the cases with which he had to deal. He has shown that they have served the purpose well. This is important, because it demonstrates that homogenous bone chips may be used as successfully as massive grafts of cortical bone.

My own experience with homogenous bone grafts has been limited to the use of full-thickness cortical grafts and entire sections of the fibula, alone or in combination. This discussion will, therefore, be limited to the use of homogenous grafts of this type.

Dr. Calvin K. Terwilliger and I, while in the Army, performed fifteen homogenous bone-graft operations on soldiers between March 1945 and March 1946. All of the patients had had at least one amputation, and two were double amputees. All had been wounded in action, and all grafts except one were done at sites where compound fractures had indicated the need for grafting. In eleven of the fifteen cases, loss of substance of the shaft of the bone was present, in addition to non-union. Two of the grafts were employed to extend the length of the humerus, in an effort to make possible the use of a prosthesis. Four others were used for non-union and loss of substance in the bones of amputated extremities, to prevent reamputation at higher levels.

The bones grafted were: humerus, five; ulna, four; radius, one; femur, two; and tibia, three. An entire section of the fibula was used alone as an intramedullary graft in four cases. The intramedullary fibular graft was reinforced with a massive full-thickness cortical graft in three cases. A massive cortical onlay graft was used alone in seven cases, and a double onlay graft in one.

The bone in each case was removed from the donor immediately before it was used on the recipient. Cross matching or grouping of the blood was not done. The donor was examined carefully for syphilis and other serious diseases. The bone used was taken from amputation stumps below the knee; these were too long and would have been reamputated anyway.

In ten of the fifteen cases thus grafted with bone from another patient, the results were classed as excellent in every respect when the patient was last seen, a year or more later. Three other patients obtained good healing, but, due to accident or undue carelessness and failure to cooperate, fracture of the grafts occurred after healing had taken place. Low-grade infections with drainage developed in the other two patients, and the grafts were lost. These two were the only complete failures.

In no case could results short of perfection be attributed to the use of homogenous bone. In fact, the results were all that could have been expected from autogenous bone grafts.

The implications of the successful use of homogenous bone are far-reaching. This is probably only the beginning of renewed interest in, and full appreciation of the value of, homogenous bone. Further use of stored bone will be necessary to determine finally whether a bone donor, in the ordinary sense, will be necessary in the future in cases in which homogenous bone is to be used.

Dr. J. S. Speed, Memphis, Tennessee: Dr. Henry has showed us many interesting uses of homogenous grafts. Dr. Alldredge, in his discussion, shows the advantages and value of this bone as a means of bridging defects and for non-union. The advantages to the patient, when homogenous bone is used, are obvious.

The use of refrigerated bone, which has not been available before, opens up a vast field in reconstructive surgery. With the use of refrigerated bone and with the ability to preserve this bone in a more or less vital state, we are able to obviate many of the disadvantages that go with massive bone surgery. Theoretically, there should be no objection to the use of refrigerated bone. Our experience with it has coincided exactly with Dr. Henry's. Our conclusions with regard to homogenous bone, as compared with autogenous bone, are that there is very little difference. Perhaps there is more tendency to absorption, and the homogenous bone resists infection less; otherwise they are the same.

Dr. Alberto Inclan, Havana, Cuba: We have been using preserved bone grafts for ten years, and we have had almost 100 cases. We have been unable to study the possibilities of frozen bone because, on account of the War, we were deprived of a freezing machine; but we are already using refrigerated bone, kept at

2 degrees centigrade in an ordinary refrigerator. We are very pleased with its use in cases of spine fusion, where it helps to avoid shock and eliminates mortality, as Dr. Henry has mentioned. We have used a great deal of refrigerated bone for bone-grafting in fractures of the neck of the femur.

When using homogenous bone, we have taken it from the donor under local anaesthesia and kept it in the refrigerator for one or two weeks, until we were ready to perform the second operation on the hip. In large defects of bone, when no autogenous bone was available, we have been able to use cancellous bone.

I am sorry I did not know this paper was on the program, so that I might have reviewed my cases beforehand.

Dr. Alan DeForest Smith, New York, N. Y.: My interest in this subject began about twenty years ago, when a patient, eleven years old, had fragilitas ossium and an ununited fracture of the shaft of each femur in the upper third, with marked deformity. It was obviously impossible to get bone from the patient. The child's mother was admitted to the hospital, and I used a massive graft from one of her tibiae, which united well. Later I did the same thing on the other hip. Subsequently, the patient was able to walk, and has had no further fractures.

Later I did a similar operation in a case of fragilitas ossium, using a relative (the mother's mother). We have used homogenous bone in cavities left by cysts and tumors, and in congenital pseudarthrosis of the hip. During the last year we have had a bone bank at the New York Orthopaedic Hospital, with a freezer which is placed at minus 25 degrees centigrade. We have used the refrigerated bone in 100 cases and found it very helpful; there have been no bad results, and all were what we would expect from the use of fresh autogenous bone.

These banks are being established all over the country. Dr. Alldredge told me that he had the first one at a British General Hospital during World War II. With homogenous bone, one should be careful to rule out infection. We do not use any bone for two weeks, and we are careful to eliminate syphilis and malaria. I do not think blood typing is necessary.

Dr. Henry has made a very important contribution and, with the possibility of preserving the bone by refrigeration, this method will have a much wider application than in the past.

Dr. J. R. Moore, Philadelphia, Pennsylvania: For the past six years, it has been our custom to employ a graft of os novum in the treatment of pseudarthrosis, particularly congenital pseudarthrosis. A graft of adequate length is removed subperiosteally from the ilium or the tibia with the motor saw, lifted from its bed to make sure it is entirely free, and then replaced. The periosteum is closed, along with the subcutaneous tissue and skin, and the graft is left in place for eighteen days in a child and for four weeks in an adult. It is then removed and used as a self-sustaining bone graft. Fixation is obtained by double pins above and below in the fracture fragments, combined with plaster-of-Paris. These delayed grafts show microscopic evidence of new-bone formation about their surfaces, and there has been a marked increase in phosphatase over the normal at the end of the eighteen to twenty-eight days. The regenerative power of these grafts appears remarkable. The use of homografts in a series of cases of congenital pseudarthrosis with a four-year follow-up will be reported shortly.

Dr. Henry's excellent presentation brings out clearly the possibilities that may be expected from the use of homografts. Their usefulness should be kept in mind constantly.

Dr. Myron O. Henry (closing): I think you will find it much easier to get donors to contribute bone from the ilium. The cases I have presented were done five, six, and seven years before Dr. Phemister told us about cancellous bone. Cancellous bone from the posterior portion of the ilium has the advantage that the donor does all the bleeding and not the recipient, which reduces the danger of shock.

THE MECHANISM OF INJURY AND THE DISTRIBUTION OF THREE THOUSAND FRACTURES AND DISLOCATIONS CAUSED BY PARACHUTE JUMPING

BY MAJOR ROY CICCONE AND CAPTAIN ROBERT M. RICHMAN

Medical Corps, Army of the United States

During the recent war years, considerable surgical interest has centered on the injuries resulting from parachute jumping. Now that the military-training program has subsided almost to peacetime levels, it is possible to supplement the earlier papers on parachute injuries [10, 13, 14, 21, 22] with a more definitive report, covering more than 600,000 parachute jumps conducted by the Airborne School at Fort Benning, Georgia. The casualties incident to this training were undeniably heavy; over 3,000 men were sent to the hospital with fractures and major dislocations, while the sprains, contusions, and lesser soft-tissue injuries were numerous almost beyond reckoning. A complete catalogue of the injuries would include such a confusing variety of lesions, some of them extremely bizarre, that the list would be merely a statistical curiosity. In order to achieve a proper perspective, therefore, this discussion will be devoted only to the more typical, recurrent patterns of injury encountered in parachute jumping, with particular attention to the traumatic mechanisms involved. The survey was facilitated by the fact that all orthopaedic casualties from the Airborne School were sent to the hospital and treated under the personal observation of the authors.

The anatomical distribution of these fractures and major soft-tissue injuries is summarized in Tables I and II. As one would expect, the injuries showed a strong predilection for weight-bearing structures; the foot and ankle, leg, femur, and spine together account for 90 per cent. of the series. The relative frequency of certain injuries, however, is different from that encountered in civilian orthopaedic practice. The series includes few fractures of the calcaneus and of the distal end of the radius, for example, although traditionally they are both associated with the trauma of falling. Fractures of the posterior tibial margin and multiple metatarsal fractures, on the other hand, are disproportionately prevalent among parachutists. The reasons for this unusual distribution of injuries become apparent when one considers their special traumatic hazards.

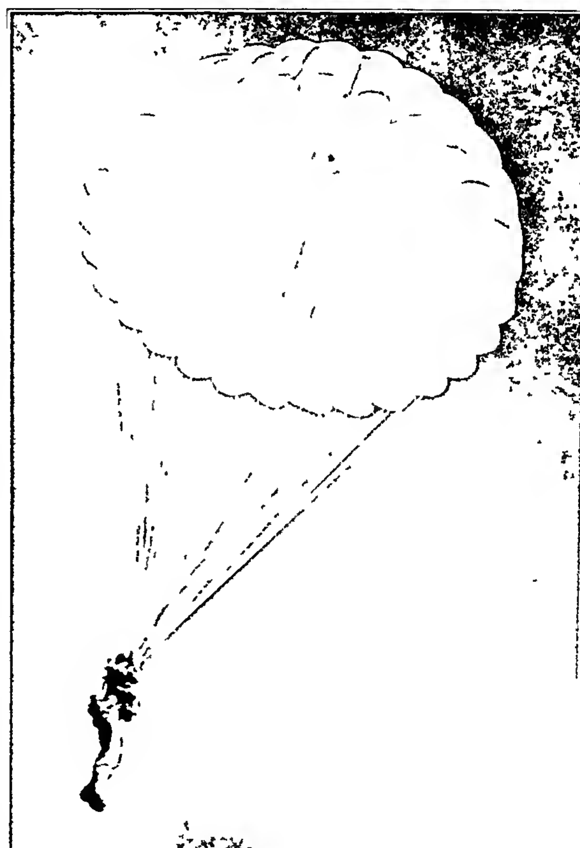

FIG. 1

Photograph of a parachutist descending correctly. Note the semiflexed, springy attitude of the legs, so that he lands on his toes rather than on the heels, and absorbs the impact against the elastic resistance of the muscles. (*Photograph by U. S. Army Air Corps.*)

TABLE I

ANATOMICAL DISTRIBUTION OF 2,709 FRACTURES DUE TO PARACHUTE JUMPING

Location	Number			Per cent.
Lower extremity			2,331	86.0
Ankle		1,462		
External malleolus alone	635			
Posterior tibial margin alone	319			
External malleolus plus posterior tibial margin	218			
Bimalleolar fracture with fracture of the posterior margin of the tibia (the "trimalleolar" fracture of Henderson [12])	112			
Internal malleolus alone	99			
Bimalleolar	60			
Others	19			
Metatarsals (total)		385		
Single metatarsal	90 cases			
Multiple metatarsals	103 cases			
Tarsals		186		
Talus	54			
Navicular	49			
Calcaneus	40			
Cuboid	27			
Cuneiform bones	4			
Phalanges	12			
Tibia and fibula (shafts)		251		
Tibia plus fibula	125			
Tibia alone	27			
Fibula alone	78			
Tibial plateau (including tibial spines)	21			
Femur		36		
Patella		11		
Trunk			206	7.6
Vertebrae (total)		168		
Single vertebrae	80 cases			
Multiple vertebrae	41 cases			
Pelvis		22		
Transverse processes of vertebrae		8		
Ribs		8		
Upper extremity			156	5.8
Humerus		38		
Shaft	16			
Greater tuberosity	22			
Clavicle		35		
Scapula		6		
Olecranon		5		
Radius (total)		26		
Head	11			
Shaft	5			
Colles's type	10			
Carpals and metacarpals		26		
Phalanges		20		
Others			16	0.6
Total			2,709	100.0

Most parachute training in this country has been conducted from the C-47 airplane, the military counterpart of the familiar DC-3 commercial transport. The sequence of events in a typical parachute jump is as follows: When the plane approaches the drop

TABLE II

Major Soft-Tissue Injuries Due to Parachute Jumping

Cerebral concussion		110
Tears of knee ligament		93
Abduction instability	88	
Adduction instability	4	
Complete dislocation (anterior)	1	
Shoulder dislocations		39
Acromioclavicular separations		23
Elbow dislocations		9
Dislocated head of fibula		8
Separations of symphysis pubis		8
Metatarsophalangeal dislocations		8
Metacarpophalangeal dislocations		3
Carpometacarpal dislocations		2
Tears of biceps muscle		2
Hip dislocation		1
Total		306

zone, it slows down to an air speed of 110 miles per hour; the jumpers stand ready; and, at a signal from the jumpmaster, they leap feet first out the door, in rapid succession (Fig. 16). As each man clears the plane, his parachute pack is ripped open automatically by a static line attached to the plane; the silken canopy unfolds, catches the air, and checks his fall with a violent but reassuring jar. This is known as the "opening shock". The jumper then floats down-wind, controlling his direction and drift to some extent by manipulating the "risers" overhead. He holds feet together, toes pointed downward, knees and hips slightly flexed, as shown in Figure 1. The muscles are not tense, but are alert to absorb the shock at the moment of impact. The parachutist is taught to land on his toes, facing down-wind so that the horizontal momentum carries him forward rather than backward. He makes no attempt to remain standing, but twists to one side like a tumbler and cushions his fall by rolling onto the muscular areas of the calf, thigh, buttocks, and back. He then throws off the parachute harness and is ready for action.

Naturally, a great deal of preliminary training is necessary in order to teach the novice how to bail out correctly, control his descent, and land without injury. A freezing fear of heights is instinctive in the untrained individual; he either lands stiff-legged and suffers a fractured heel, or lunges forward on outstretched hands and pays for this mistake with a fractured wrist. Parachutists are specifically trained to avoid these errors. All phases of the actual parachute jump, from the opening shock to the landing impact, are simulated by special apparatus, so that ultimately the smooth follow-through to a cushioned-landing fall becomes an automatic response.

Despite the most thorough training, however, there are certain inescapable hazards beyond human control, which magnify the risks of parachute jumping. Chief among these is excessive wind velocity. Jumping on a windy day is somewhat like leaping from the top of a moving train; besides the force of gravity, there is an additional horizontal drift that greatly increases the shock of landing. Furthermore, the wind invariably sets up "oscillation", so that the jumper swings back and forth beneath the parachute like a pendulum and may strike the ground from an unpredictable and dangerous angle. Occasionally, jumpers drift together and become entangled, collapsing each other's parachute and falling the last fifty feet or so with great violence. Tree landings, rough terrain, and the opening shock also take their toll of injuries. Even with all of these "occupational" hazards, it is remarkable that the rate of over-all injury at the Airborne School during the past two years has consistently been less than one casualty per hundred jumps[14]; and

TABLE III

INJURIES DUE TO EXTERNAL ROTATION PLUS LANDING THRUST

Location	Injury
Foot	Dorsal dislocation of the toes Metatarsal fractures, multiple or single Compression fractures of mid-tarsal bones
Ankle	Oblique fracture of lateral malleolus Vertical fracture of posterior tibial margin Combined fracture of lateral malleolus and posterior tibial margin Diastasis of tibiofibular syndesmosis Bimalleolar fracture with fracture of the posterior margin of the tibia at the ankle Bimalleolar fracture Solitary fracture of internal malleolus Various combinations of malleolar fractures with leg fractures
Leg and knee	Spiral fracture of shaft of tibia Oblique fracture of shaft of neck of fibula Combined spiral fractures of tibia and fibula Dislocated head of fibula Tear of medial meniscus of knee Tear of medial collateral ligament of knee
Thigh	Spiral fractures of shaft of femur Fracture of neck of femur

even this low figure is declining steadily, due to constantly improved training techniques and safety precautions.

When one reviews the injuries listed in Tables I and II in the light of the clinical findings and history, it becomes evident that almost all of them can be attributed to only four recurrent traumatic mechanisms: (1) torsion plus "landing thrust", (2) backward landing, (3) opening shock, and (4) violent vertical fall. These, with minor variations, are the main causes of injury in parachute jumping. It is proposed to explain these mechanisms, discuss the underlying traumatic stresses in detail, and illustrate the specific lesions for which each is responsible.

It should be admitted at the outset that the clinical evidence regarding traumatic stresses is largely circumstantial. Obviously, there is no opportunity to observe the accidents at first hand under controlled conditions. Also, the patients' histories are notoriously inaccurate, and usually too vague to furnish any reliable information about the nature of the trauma. Some investigators have attempted to analyze traumatic stresses on the cadaver, but the results of their experiments are not entirely applicable, since it is impossible in the laboratory to duplicate all the complex muscle leverages, and the impact of the actual landing. In the absence of more direct evidence, therefore, one is forced to rely upon clinical observations and to deduce the etiological trauma from the injury. Sometimes this is easy; the gross distortion of the limb may identify the stress. Soft-tissue swelling is also suggestive, especially early after injury, before it has had time to diffuse. The roentgenograms are particularly valuable; the direction of fracture lines—oblique, spiral, or transverse—the displacement of fragments, impaction, comminution, chip fragments, and many other signs, all characterize the antecedent stress. The most characteristic and conclusive proof of the mechanism, however, is elicited in the course of treatment. At this time, one can test the fragments under anaesthesia, first carefully exaggerating the distortion and then reducing it, and in this way determine the forces which were

Fig. 2

Shows the mechanism of external-torsion fractures and two classical fractures. The great majority of parachute fractures are of the external rotation or abduction type.

responsible for the injury. Admittedly, the method has its limitations, but by integrating all the bits of evidence outlined, it is possible to recognize the underlying stresses of each of the traumatic mechanisms from the injuries they produce.

TORSION PLUS "LANDING THRUST"

This is by far the most common mechanism of injury, since it represents an exaggeration of the forces normally encountered in parachute landing. As explained earlier, the parachutist descends with a downward and forward momentum, gravity and wind drift contributing, respectively, the main vertical and horizontal components. At the moment he strikes the ground, there is generated against his feet an upward and backward reactive thrust—which we call the "landing thrust"—and, in addition, various torsional stresses, due to uneven ground and the ever-present oscillation. Under normal conditions, these stresses are not violent enough to cause injury; the impact is transmitted through the foot and ankle and dissipated against the elastic resistance of the muscles and supporting structures. When the same landing stresses are exaggerated by unfavorable jumping conditions, however, they may exceed the physical tolerance of the body, disrupt the supporting structures, and produce a wide variety of fractures, sprains, and dislocations (Fig. 2).

In the list of lesions, external-torsion injuries far outnumber those due to internal torsion. Without a digression into detailed functional anatomy, it would appear that the supporting structures are more yielding in the direction of internal rotation, whereas they are more rigid and consequently more vulnerable under the stress of external rotation. This is not an original observation. Ashhurst and Bromer have emphasized the statistical predominance of external-rotation injuries in their scholarly and well-documented study of ankle fractures. On the basis of our large series of injuries, it is proposed to extend Ashhurst and Bromer's conclusions and to show how external rotation, in combination with varying degrees of landing thrust, is responsible for a chain of injuries not only involving

the ankle, but also extending the entire length of the lower extremity from the toes to the hip. These injuries differ widely in pattern, as well as location, yet all are related by a common denominator, the same etiological mechanism. Some of the more typical injuries are listed in Table III.

Naturally, the specific lesion in each case depends upon the relative intensity of the traumatic stresses. A predominant landing thrust, for example, would crush the midtarsal bones, or drive the talus posteriorly in the ankle mortise and split off the posterior tibial margin. Predominant torsion stress, on the other hand, would be likely to rupture the tibiofibular ligaments, fracture the distal end of the fibula, or cause a spiral fracture of the shafts of both tibia and fibula. Theoretically, one could postulate infinite combinations and permutations of the traumatic stresses, and hence an unlimited variety of lesions; but fortunately, the problem is simplified by the fact that the statistical distribution of injuries favors certain recurrent clinical patterns—"classical" injuries, so to speak—around which this discussion will center.

External-Rotation Injuries

The oblique fracture of the distal end of the fibula has long been recognized as the prototype of this mechanism of injury. Its historical background and varied interpretation have been admirably described by Ashhurst and Bromer. It is an extremely common parachute injury; alone and in combination with other lesions, it is found in more than two-thirds of all our fractured ankles. The lesion is seen in Figure 3 as an oblique crack, extending from the anterior border of the lateral malleolus upward and backward across the tibiofibular syndesmosis to the posterior aspect of the shaft of the fibula. Often the fracture line is invisible in the standard anteroposterior roentgenogram, but it can be accentuated by reapplying the traumatic stress,—that is, by forcing the foot into external rotation. The foot then acts as a rigid lever, twisting the talus, which in turn crowds the

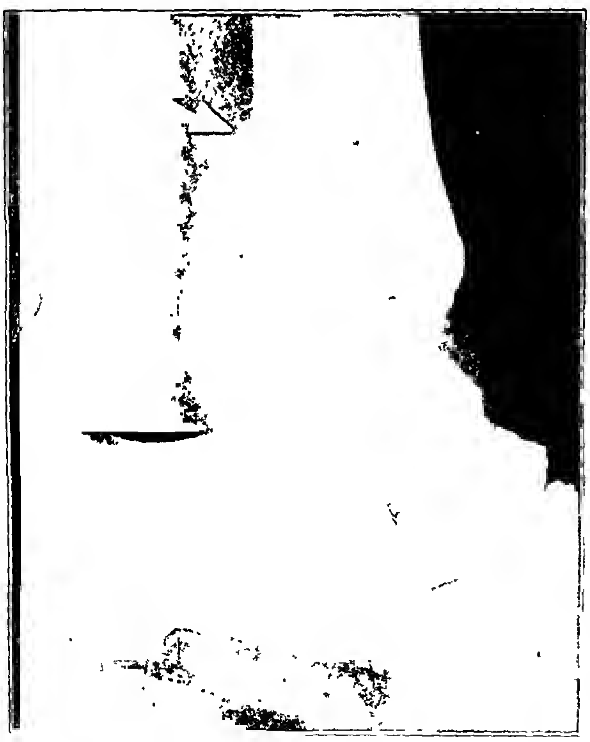

Fig. 3

Fig. 4

Fig. 3: The solitary low oblique fracture of the fibula is the most common parachute fracture and, indeed, the most common ankle fracture, regardless of the circumstances of injury. In this case, displacement is negligible, and the fracture line could barely be detected in the anteroposterior view.

Fig. 4: Avulsion chip fracture of the posterior process of the talus at the site of attachment of the posterior talofibular ligament. The fragment is suggestive of an os trigonum.

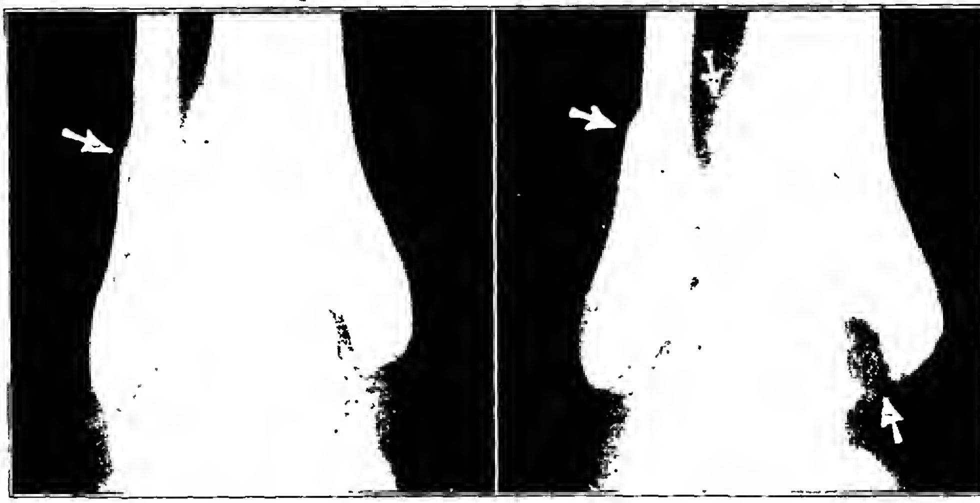

FIG. 5-A FIG. 5-B

An oblique fracture of the fibula, combined with tears of the deltoid and tibiofibular ligaments (as evidenced by the subperiosteal chip avulsed from the lateral border of the tibia). Fig. 5-A, taken with the foot in the standard neutral position, shows very little widening of the mortise. In Fig. 5-B, the foot is being externally rotated and abducted in order to demonstrate the latent diastasis.

FIG. 6-A FIG. 6-B

Every sprained ankle should be tested for instability. In Fig. 6-A, this injury might be accepted as an ordinary "sprained ankle", with a chip avulsed from the medial malleolus. When the foot is forced into external rotation, however, the mortise gapes medially, and the tibiofibular diastasis becomes apparent. These are serious injuries, with a high incidence of "weak-ankle" disability and premature arthritic changes.

lateral malleolus laterally and simultaneously pulls it backward, through tension on the posterior talofibular ligament. The combined push-pull stress on the fibula displaces the malleolus posterolaterally and widens the ankle mortise (Figs. 5-A and 5-B). There is frequently a coexisting tear of the tibiofibular ligaments, which aggravates the tendency to diastasis.

Since the lesion is produced by external rotation, it is only necessary to maintain the foot in slight internal rotation until healing is complete. Unfortunately, the customary short-leg plaster boot often fails to do this. As the initial swelling subsides and the calf muscles atrophy, the boot becomes quite loose and no longer protects the mortise against the spreading effect of day-to-day torsional stresses. It is not surprising, therefore, that

occasionally one finds "healed" cases which display appreciable widening of the mortise, with all its attendant disability[12], even though the roentgenograms taken immediately after reduction demonstrated good position in the cast. The worrisome feature of these injuries is more the diastasis than the fracture itself; consequently, in those cases which show any tendency to diastasis, it would seem advisable to extend the cast up to the groin, so as to immobilize the knee in semiflexion and hold the foot securely in internal rotation until the mortise is stable. When callus can be demonstrated and when diastasis can no longer be elicited, it is safe to change to a short leg boot.

The medial malleolus is also vulnerable to external-rotation stress, either as a solitary lesion or as part of a bimalleolar fracture. Ashhurst and Bromer are inclined to regard most solitary fractures of the medial malleolus as abduction injuries; but, while abduction doubtless plays a role through tension on the deltoid ligament, the present authors believe that the obliquity of the fracture line and the anterior displacement of the malleolar fragment (pointed out by Stevens) suggest primarily a torsion mechanism. In the light of our imperfect evidence on traumatic stresses, however, it would be presumptuous to draw a hard and fast line between abduction and external rotation. Strictly speaking, there is a *distinction: External rotation signifies an outward deviation of the point of the foot* around the longitudinal axis of the leg, whereas abduction signifies an outward deviation of the sole around an anteroposterior axis through the mortise. In practice, however, the distinction becomes artificial, since these movements take place simultaneously and shade into each other so gradually that one cannot say where abduction leaves off and external rotation begins. They are functionally very closely related; indeed, Whitman used the terms synonymously. Clinically, one can recognize many more "pure" external-rotation than abduction injuries, and so we have included abduction stresses under this heading.

Fig. 7

Fig. 8

Showing a pair of external-rotation injuries,—spiro-oblique fractures of the lower portion of the tibia and the upper portion of the fibula. Usually these occur in combination, although here they happened to be solitary fractures.

Ligamentous injuries due to external rotation are very common, not only as complications of malleolar fractures, but also as solitary lesions of major significance in their own right [1,6]. Two of the more important lesions are tears of the deltoid ligament and of the inferior tibiofibular ligaments. These structures are intimately related to the integrity of the ankle mortise; any widening of the tibiofibular syndesmosis or lateral displacement of the talus is necessarily accompanied by disruption of one or both of these ligaments. Unfortunately, the extent of the damage, particularly in tibiofibular diastasis, is usually not apparent in the routine roentgenograms, since by the time the patient arrives at the hospital, with his boots off and emergency splints already applied, the diastasis has been reduced spontaneously, and there is nothing to be seen but soft-tissue swelling. For an accurate appraisal of the ligamentous damage, it is necessary to manipulate the joint under anaesthesia and to supplement the standard roentgenograms with special views to demonstrate any latent instability of the mortise [23] (Figs. 6-A and 6-B).

FIG. 9

Fracture of the upper third of the fibula with diastasis of the ankle mortise, a combination described by Maisonneuve. This patient was not a parachutist; he fell from a ladder and landed sitting on the *outer* side of the left leg. The stress was evidently external rotation plus abduction. (Drawn from roentgenograms loaned by Arthur Krida, M.D., Director of the Orthopaedic Service, Bellevue Hospital, New York City.)

Pure external-rotation injuries of the foot are uncommon, except for one interesting lesion,—avulsion fracture of the posterior process of the talus (Fig. 4). This is caused by excessive tension of the talofibular ligament, a strong structure that moors the fibula against the side of the talus. Under external rotary stress, this ligament, which itself is very resistant to injury, occasionally avulses its bony insertion to form a fragment resembling an os trigonum.

Proceeding up the leg, we find that the typical pattern of injury is a spiral fracture of the shafts of both bones, the tibia breaking at the juncture of the middle and lower thirds, and the fibula usually breaking in its upper third, or even through the neck (Fig. 2). This is a familiar lesion, encountered in skiing, football, and many other sports; and the torsional etiology is thoroughly established [17]. Indeed, the spiral pattern of fracture is characteristic of the failure of a brittle rod under torsion stress. If further confirmation of the mechanism were needed, it might be observed, during open reduction of the fractured tibia, that internal rotation reduces the fragments, whereas external rotation duplicates the original displacement. These spiral fractures, then, are etiologically similar to the external-rotation fractures of the foot and ankle, except that the disruptive effect of the torsion is manifested at a higher level.

Not all fractures of the leg involve both bones; occasionally the tibia alone fractures in the same characteristic location and spiral pattern (Fig. 7). Displacement in these cases is less severe than when both bones are broken, and the prognosis is much more favorable, since the intact fibula functions as an internal splint.

Isolated fractures of the fibula may occur anywhere along the shaft, or even obliquely through the head (Fig. 8). They are often associated with a diastasis of the tibiofibular syndesmosis, as pointed out by Maisonneuve, who apparently never encountered such a combination clinically, but nevertheless predicted it as an external-rotation injury. The presence of a high fibular fracture, therefore, should prompt the surgeon to examine the ankle for the other half of the combination. Generally, the ligamentous lesion at the ankle is minor, but sometimes it is so gross a dislocation that it completely overshadows the

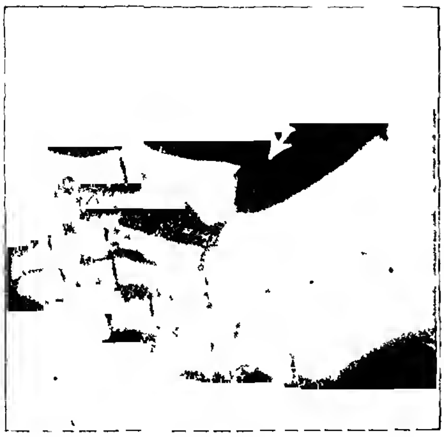

FIG. 10-A

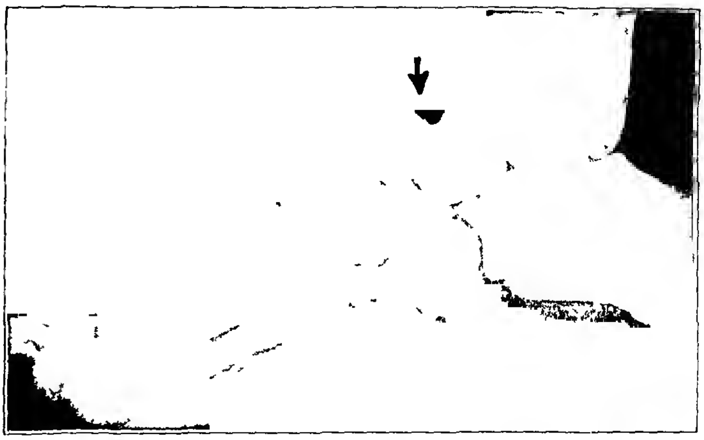

FIG. 10-C

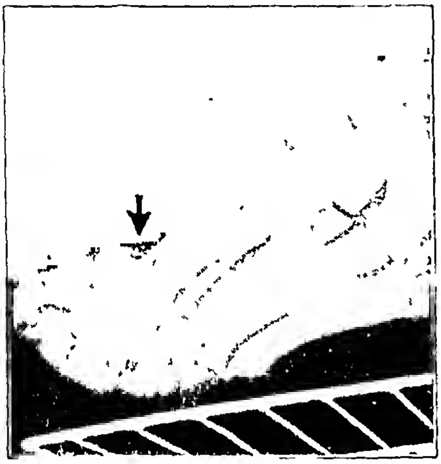

FIG. 10-B

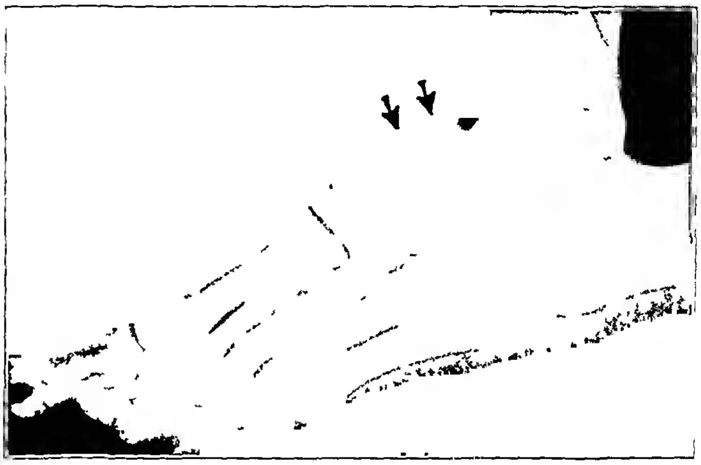

FIG. 10-D

Injuries due to "landing thrust". The impact is transmitted through the long axis of the foot and produces a chain of compression fractures of the metatarsal and tarsal bones. The next vulnerable structure is the posterior tibial margin (see Fig. 11).

fibular fracture, which may show in the roentgenogram as an unexpected finding (Fig. 9).

External torsion is definitely a factor in the common meniscal and ligamentous injuries of the knee, and also in the rare dislocations of the head of the fibula[14], which, in the authors' opinion, represent simply a variant of the torsional fractures of the head and neck of the fibula. Most of the serious tears of the knee ligaments were due to abduction stress during the opening shock, and will be discussed later in connection with that mechanism. Fully half of the fractures of the femoral shaft also were caused by the opening shock; the remainder were attributed to excessively violent landings, although there was almost invariably a spiral pattern, indicating an element of rotation as well. Even the neck of the femur is not immune to external-rotation stress. One encounters very few of these fractures in young men, but it is pertinent to recall Astley Cooper's observation that they are due, not to a fall on the greater trochanter, as is so commonly taught, but to outward rotation of the lower extremity. They represent, therefore, the uppermost link in the chain of external-rotation fractures.

Landing-Thrust Injuries

This stress has been elevated to the status of a primary traumatic mechanism by virtue of its prevalence in parachute jumping. Some of the resultant patterns in the foot are illustrated in Figures 10-A, 10-B, 10-C, and 10-D: dorsal dislocation of the great toe, fracture of the flexor sesamoid, impaction of the metatarsals, or crushing of the mid-tarsal bones, especially the navicular, which is frequently shattered by the hammer-like head of the talus under the terrific impact of landing.

Fig. 11

Fig. 12-A

Fig. 12-B

Fig. 11: A solitary vertical fracture of the posterior tibial margin. Displacement is characteristically slight; any posterior dislocation of the foot is almost invariably accompanied by a fracture of the fibular malleolus. (Compare with Fig. 12-B).

Figs. 12-A and 12-B: A pair of bimalleolar fractures with fracture of the posterior margin of the tibia. In Fig. 12-B, the component of landing-thrust stress is more evident, and there is frank posterior dislocation of the foot.

If the metatarsal and tarsal bones survive the force of the landing thrust, the next vulnerable structure is the posterior tibial margin, which receives the upward and backward impact directly from the talus and frequently splits off vertically as a triangular fragment (Fig. 11). Usually only a small portion of the tibial articular surface is detached, and since the ligamentous arrangement of the ankle is especially designed to resist backward dislocation of the talus [11], displacement of the fragment is generally slight.

Solitary fractures of the posterior tibial margin were described as far back as 1909 by Meissner, rediscovered in 1915 as "Cotton's fracture" [8], and again rechristened during the War as the "paratrooper fracture" [13,21]. The authors feel that this term is hardly justifiable, since the fracture is not unique among parachutists, but is apt to occur under any circumstances when the body falls forward as well as downward [12,15]. Although posterior marginal fractures occur more often in combination with external-rotation injuries, the fact remains that they do exist as isolated primary lesions, so there is little reason to classify them as a "variant" or "third degree" [5] of external-rotation fractures. They show none of the morphological characteristics of torsional injuries. The mechanism is evident: Stevens' designation of "impact splits" is accurately descriptive, although the term "landing thrust" may be preferred, since it suggests the specific direction of impact, and also links these injuries generically with the impaction fractures of the metatarsal and tarsal bones.

Injuries of External Rotation Plus Landing Thrust

At the ankle, this mechanism is characterized by posterior marginal fractures, combined with any of the lesions produced by external torsion. All sorts of combinations and variations are possible, but the most common clinical patterns are the fractures of the lateral malleolus plus the posterior margin and the bimalleolar fractures with fracture of the posterior margin of the tibia (Figs. 12-A and 12-B). In contrast to the undisplaced fractures of the posterior margin, these multiple fractures are often complicated by posterior dislocation of the foot, since there is so much disruption of the mortise that its inherent stability is destroyed. Neither the bones nor the ligaments can provide effective support. Even after reduction, the foot tends to sag backward under its own weight,

Fig. 13-A

Fig. 13-B

Fig. 13-C

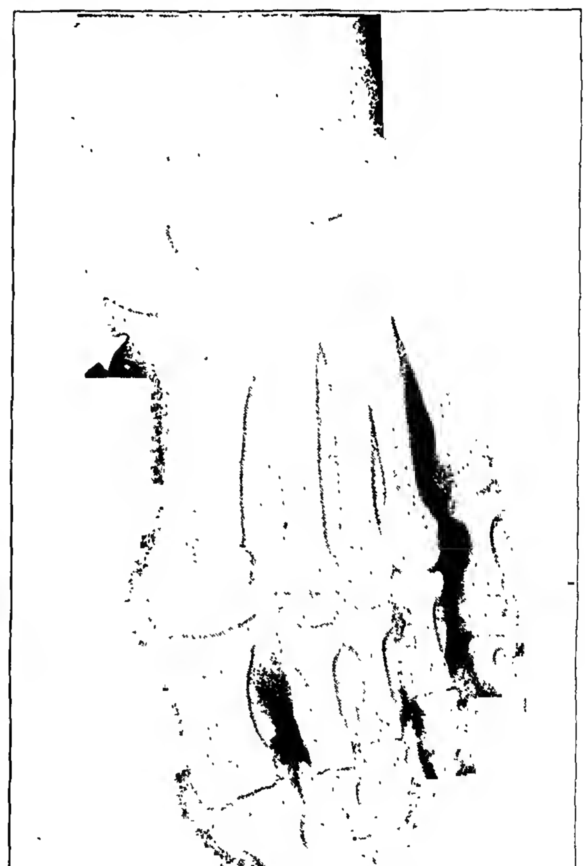

Fig. 13-D

More lateral displacement is shown here than in Figs. 10-A, 10-B, 10-C, and 10-D, indicating an element of external rotation in addition to the landing thrust. Multiple metatarsal fractures are particularly common, as shown in Fig. 13-B.

aggravated by muscle pull from the calf. This leads to a chronic posterior subluxation of the foot, distortion of the tibial articular surface, and permanent arthritic disability. There is abundant literature concerning these injuries, especially the "trimalleolar"

TABLE IV

MECHANISM OF INJURY IN 300 ANKLE FRACTURES

	No. of Fractures	Totals
External rotation (including abduction)		157
Oblique fracture of lower end of fibula	128	
Oblique fracture of fibula plus fracture of anterior tibial tubercle	2	
Medial malleolus	13	
Medial malleolus plus oblique fracture of fibula	13	
Medial malleolus plus comminuted fibula (abduction)	1	
External rotation plus landing thrust		83
Oblique fracture of fibula plus fracture of posterior tibial margin	55	
Medial malleolus plus posterior tibial margin	2	
Bimalleolar fracture plus fracture of posterior tibial margin	25	
Shafts of tibia and fibula (spiral) plus posterior margin	1	
Landing thrust		47
Solitary fracture of posterior tibial margin	47	
Adduction		8
Transverse fracture of lateral malleolus (excluding chip fractures)	3	
Bimalleolar fractures	4	
Medial malleolus	1	
Vertical compression		2
Extensive comminution of lower ends of tibia and fibula	2	
Undetermined mechanism		3
Total		300

fractures[12]. Many surgeons advise open reduction of the mortise and internal fixation of at least the medial malleolus and the posterior margin of the tibia; but whatever method of treatment is selected, reduction must be exact. It is essential to support the talus well forward under the tibia, and to secure an accurate realignment of the weight-bearing axes.

Metatarsal fractures (Fig. 13-B) form a notable group of injuries. Due to the special landing technique of parachutists, these fractures are much more prevalent than in civilian life, and in half of the cases there is more than one fracture in the same foot. They show a characteristic dorsolateral shearing and impaction of the metatarsal heads. Occasionally, there are superimposed injuries, such as cuboid fractures or the unusual split foot (Fig. 13-C), which confirm the "sideswiping" stress of external rotation.

In addition to the typical torsion fractures of the leg, described earlier, there are less frequent transitional fractures, showing characteristics of posterior thrust as well as of torsion. In some cases, a triangular fragment is detached from the posterior aspect of the shafts, in others, spiro-oblique fractures of the tibia and fibula are combined with vertical fractures of the posterior tibial margin. These combined lesions of the leg and ankle illustrate the fallacy of attempting to classify fractures according to their location rather than their underlying mechanism. Trauma does not respect the arbitrary boundaries between the foot, ankle, and leg We have already seen that the same stress can produce multiple lesions at widely different levels Furthermore, a geographic classification inevitably becomes involved and cumbersome. Consider, for example, Maisonneuve's fracture,—a diastasis of the tibiofibular syndesmosis combined with a fracture of the upper shaft of the fibula. Is this primarily an "ankle" lesion or a "leg" lesion? Certainly the diastasis at the ankle is of more serious consequence than the fractured fibular shaft. In an etiological classification, however, these anatomical considerations are of secondary importance, since both lesions fit into one category,— namely, external rotation.

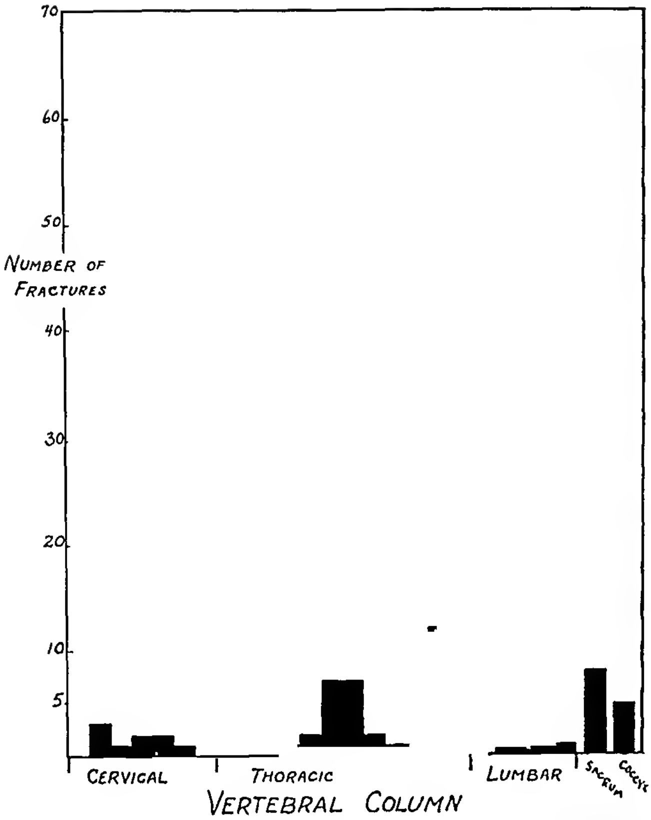

Chart 1

Fig. 14

Chart 1: Distribution frequency of vertebral compression fractures. Most of the fractures are concentrated at the thoracolumbar juncture. (Fractures of the second cervical vertebra are all of the odontoid process.)

Fig. 14: Roentgenogram shows fracture of the mortise, due to adduction stress. The medial malleolar fragment is reminiscent of fractures of the posterior tibial margin. Both show a nearly vertical split, indicating direct thrust of the talus against the overhanging lip of bone.

Adduction and Internal Rotation

The most common result of adduction stress is the ordinary "sprained ankle",—that is, a tear of the fibulocalcaneal ligaments, often with a subperiosteal chip avulsed from the end of the fibula. Here, too, the important distinction must be made between partial tears and complete rupture of the ligament, since the presence of instability implies a totally different treatment and prognosis. Adduction fractures of the malleoli comprise less than 3 per cent. of our ankle fractures. They present a distinctive picture: a transverse fracture of the fibula at the level of the joint line, and a vertical split of the tibia through the medial angle of the mortise (Fig. 14). These fractures do not necessarily occur together; each has been observed as a solitary lesion.

Internal rotation probably contributes to most of the adduction fractures, but as a pure stress it has not yet been correlated convincingly with any specific injuries.

Summary

In order to recapitulate our experience with fractures of the ankle mortise, the authors have reviewed the last 300 fractures of the ankle; correlated the clinical, roentgenographic, and operative findings; and tabulated the injuries according to the traumatic mechanism (Table IV). As explained earlier, this arrangement depends upon the interpretation of circumstantial evidence, and one must beware of straining such evidence too far by postulating a theoretical sequence of trauma, or by intricate subclassifications, or tortured analogies with the laws of mechanics. The authors have tried to avoid these pitfalls of speculation. Table IV merely groups the fractures under well-recognized mechanisms, and it is with these mechanisms rather than with the minor variations in pattern that we are primarily concerned.

FIG. 15

Backward landings are dangerous. The parachutist's feet are swept out from under him, so that he lands directly on his buttocks; and the entire impact is transmitted to the spine.

A comparison of this cross section of the series with other reported groups of ankle fractures indicates that it makes little difference whether the ankle is broken by falling downstairs, stepping off a curb, playing football, or parachute jumping: From the point of view of *etiological stresses*, the statistical distribution of fractures is much the same. There are certain minor variations, such as the high incidence of posterior marginal fractures of the tibia, and the relatively low incidence of vertical compression fractures in this series. These differences, however, are trivial; the fundamental point of similarity is the preponderance of external-rotation injuries. External rotation and abduction, taken together, account for 75 per cent. of the fractures reported by Ashhurst and Bromer, Stevens, Moritz, and Bishop, as well as the present authors. This cannot be mere coincidence; the figures are consistently too high, and they are independent of the source of the patients or the circumstances of injury. One may reasonably conclude, therefore, that the vulnerability of the ankle to external rotation represents an inherent weakness of the joint,—either a local structural weakness, or else a lack of adaptive resiliency of the leg as a whole. This latter possibility gains support from the fact that not only the ankle, but the entire lower extremity, shows a statistical preponderance of external-rotation injuries.

BACKWARD LANDING

The second prime cause of injury among parachutists, especially among novice jumpers, is the backward landing. Again the hazard is oscillation: The jumper strikes the ground at the peak of a pendulum-like backswing; his feet are swept out from under him; there is no opportunity to roll or to cushion his landing; and he falls abruptly backward onto his buttocks and head (Fig. 15).

Vertebral fractures and craniocerebral injuries characterize this mechanism of injury. Practically all the vertebral fractures are of the compression type, the cancellous bone being crushed anteriorly by violent hyperflexion of the spine. Almost invariably, the superior surface of the vertebral body is compressed downward toward the inferior surface.

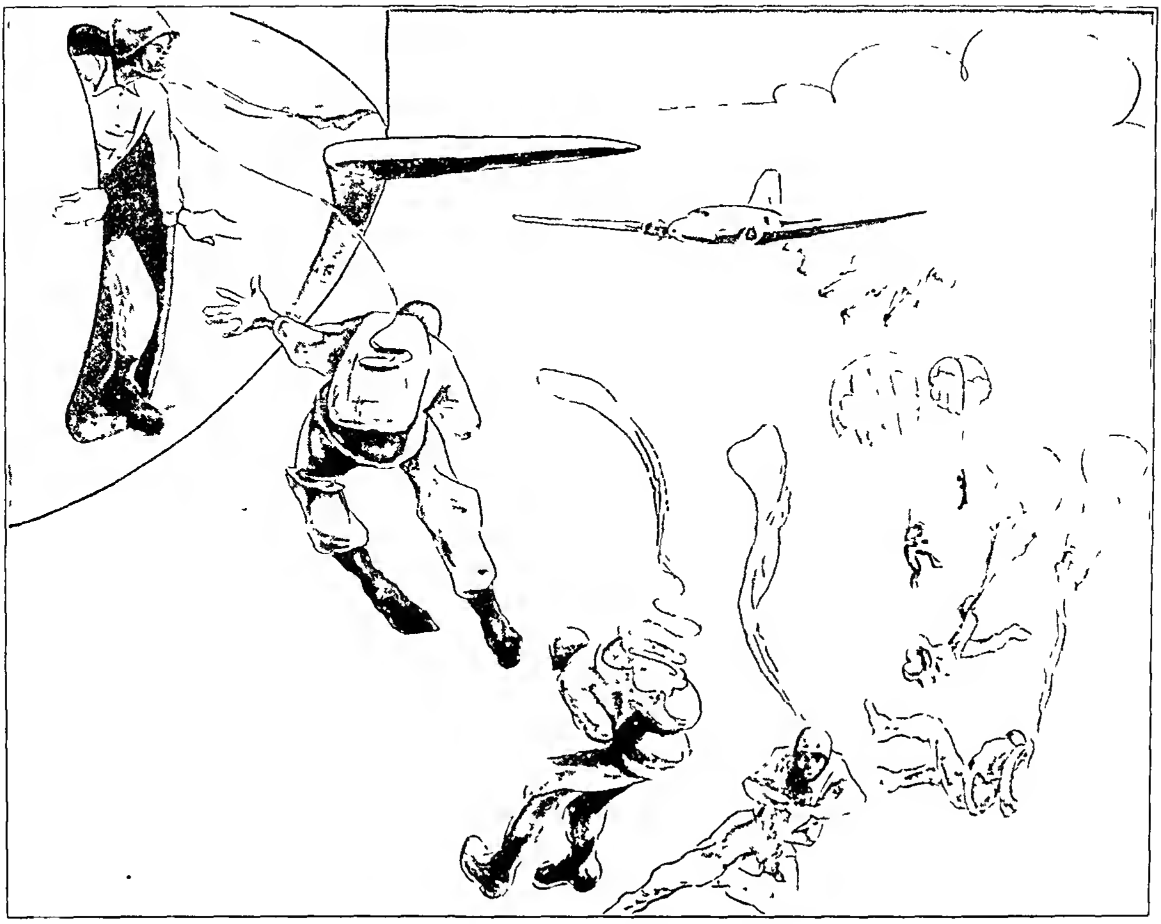

FIG. 16

As they rush out the door, parachutists occasionally trip and fall with poor body position. This composite drawing, made from slow motion pictures, illustrates several faulty positions which can cause opening-shock injuries. The third man from the plane, for example, has spun around too far and will receive a violent jerk when his parachute opens. The fifth man has caught his left leg in the suspension lines and will probably rupture the ligaments of the knee.

Fractures are not distributed uniformly throughout the spinal column. As indicated in Chart 1, the thoracolumbar segment is most commonly involved, particularly the first lumbar vertebra, and there is a secondary frequency peak in the mid-dorsal region.

One third of the cases show multiple fractures, not always in adjacent vertebrae. Paraplegia and dislocations were, fortunately, quite rare in our series. The absence of cord damage made it possible to treat all the thoracolumbar fractures by means of free hyperextension between two tables, according to the Watson-Jones technique. We consider this to be the method of choice for securing full reduction (that is, re-expansion) of the collapsed vertebral bodies.

Almost as potent a source of disability as the fractures themselves were the soft-tissue injuries of the spine,—the low-back sprains, herniated intervertebral discs, contusions of the coccyx, traumatic myositis, et cetera. It is difficult to assess the frequency of these injuries. Most parachutists are inclined to make light of minor injuries, and do not seek medical treatment unless they are practically disabled. Consequently, hospital statistics do not give a true picture of the situation. As an estimate, however, there were probably ten soft-tissue injuries of the spine for every compression fracture. Most of them may appear trivial at first, but the sequelae are notoriously troublesome, and in many men chronic low-back pain developed which ultimately disqualified them from further parachute duty.

Sometimes these backward landings are so violent that, even with the protection of a special helmet, the parachutist is knocked unconscious when his head slams against the ground. A survey of the hospital records revealed 110 cases of head injury, ranging in severity from a momentarily dazing concussion to cerebral laceration and fatal intra-

Fig. 17-A

Fig. 17-B

Fig. 17-C

Fig. 17-A: Diastasis of the symphysis pubis. Fig 17-B: Spiral fracture of the femur.
Fig. 17-C: Rupture of the medial collateral ligaments of the knee
All of these opening-shock injuries are caused in the same way: The parachutist's left leg becomes entangled in the suspension lines and, when the parachute opens and suddenly checks his fall, the shock is transmitted to the leg as a violent abduction stress.

cranial hemorrhage. Doubtless many others occurred; but, as with other soft-tissue juries, the milder cases were not reported, and the men recovered without benefit hospital treatment. Head injuries will not be discussed here, since they are prim neurosurgical problems, particularly in view of the incidence of residual headaches other distressing sequelae.

OPENING SHOCK

As a mechanism of injury, the opening shock is unique in that there is no co with the ground or with any other unyielding object; the damage is done in mid-air b sudden snubbing action of the parachute against the momentum of the falling body. likelihood of injury depends upon the position of the parachutist's body at the moment parachute opens: If he has jumped from the plane correctly, the shock is well distrib by the harness and is absorbed with little discomfort; but if he dives, somersaults, or s into a vulnerable body position, the violent jerk of the parachute can be very dangero

There are two general types of injury:

1. *Whip-lash:* Here the jumper is out of line with the tug of the opening parachu which flips him upside down with a sort of whip-lash effect. Relatively minor injuries a the rule, such as sprains of the neck, transient neuropathies of the brachial plexus [19], a ecchymotic brush burns over the clavicles from the slap of the "risers".

2. *Suspension-Line Injuries:* Occasionally an arm or leg becomes entangled in t suspension lines while the parachute is unfurling from its pack (Fig. 16). Before the jump can disentangle himself, the slack lines suddenly pull taut and wrench the extremity wi great violence, rupturing ligaments, muscles, and even the bones themselves (Figs. 17- 17-B, and 17-C). The magnitude of the stress is attested by the fact that over half t fractures of the humerus and 40 per cent. of the fractures of the femur were caused mid-air by this bizarre mechanism. Even more common were tears of the medial collater and cruciate ligaments of the knee; over sixty-five of these cases with frank instabilit have already been reported in some detail [18]. Other very serious injuries were encountere such as dislocation of the shoulder (ten cases), diastasis of the symphysis pubis (three case as well as an additional case reported by Anderson), laceration of the perineum and re tum [14], tears of the biceps and coracobrachialis muscles, and even amputation of a finge This last accident occurred when the suspension lines caught underneath a ring and avulse the entire digit. Opening-shock injuries will not be discussed further here, since they a primarily the concern of the military surgeon; from an etiological point of view, they ha no counterpart in civilian life at the present time.

VIOLENT VERTICAL LANDINGS

The American combat parachute assembly is designed to provide a normal rate of fa of twenty feet per second. This is subject to some variation, depending upon the gros weight of the parachutist and his equipment; but, if there is not too much ground wind o oscillation, the landing impact is reasonably safe,—equivalent to that of a seven-foot dro

Unfortunately, however, the rate of fall is not always so gentle. There are occasiona mishaps, rather euphemistically termed "malfunctions", in which the parachute fails t inflate properly and the rate of vertical fall is accelerated dangerously. This can happen a number of ways: The suspension lines may become tangled or fouled across the para chute, a panel of the silken canopy may be ripped by the force of the opening shock, or th jumpers may drift too close together and, like sailboats, spill the air from each other' parachute.

Regardless of the technical details of the accident, the ultimate effect is th same: The normal parachute support is reduced, the landing impact is exaggerated fa beyond the structural resistance of the body, and extremely severe and often spectacula injuries result. A few cases will serve to illustrate the general nature of the group:

Fig. 18-A

Fig. 18-B

Both of these injuries are due to indirect violence. The high fibular fracture, the low tibial fracture, and the spiro-oblique patterns of Fig. 18-A characterize it as a torsion injury. In Fig. 18-B, the transverse fracture lines, the comminution, and the fact that both tibia and fibula broke at the same level indicate that the injury was due to axial-compression stress. This is the pattern seen in the violent vertical landings.

Case 1. This patient became entangled with another parachutist in mid-air. The following injuries esulted: (a) compression fracture of the first lumbar vertebra; (b) fracture-dislocation of the body of the ourth lumbar vertebra; (c) comminuted fractures of the shafts of the left tibia and fibula; (d) multiple fracures of the pelvis, involving the right acetabulum and left pubic rami; (e) multiple fractures of the right arsal bones, including the talus, superior border of the calcaneus, the navicular, and the head of the fifth netatarsal; and (f) cerebral concussion.

Case 2. A delayed parachute opening was responsible for (a) compression fractures of the first and second umbar vertebrae; (b) transverse fractures of the shafts of the left tibia and fibula (Fig. 18-B); and (c) cominuted fracture of the mid-shaft of the right fibula.

Case 3. A violent landing, of undetermined cause, produced (a) compound fracture of the shaft of the right femur, and (b) simple fracture of the shaft of the left femur.

Case 4. This man became entangled with another parachutist in mid-air, and suffered the following injuries: (a) comminuted intertrochanteric fracture of the left femur, and (b) comminuted fractures of the shafts of the left tibia and fibula.

These injuries have little in common, except that they are multiple and involve the major weight-bearing structures, especially the long bones and vertebral column. Many of

the vertebral fractures are apparently produced by violent "jackknifing" into a squatting position, instead of a simple fall onto the buttocks. Some of the fracture patterns due to vertical compression are fairly distinctive. The tibia and fibula, for example, do not show the smooth spiral patterns characteristic of torsion fractures; instead, the bones break transversely at the same level, usually with extensive comminution (Figs. 18-A and 18-B). Occasionally, the lower end of the tibia is shattered completely in a T or Y fashion, but this does not occur so frequently as one might expect; a more common lesion in this location is a simple impact split of the *anterior* tibial border [15]. Another favorite lesion is a transverse shearing fracture through the neck of the talus.

Remarkably few fractured heels were encountered. Most of those listed in Table I were minor cracks or chips, rather than the severe compressions that one would expect from such violent landings. No doubt this is due to the fact that parachutists are trained to land with the legs semiflexed and springy, as shown in Figure 1, which permits the impact to be absorbed in the muscles and so spares the calcaneus from the crushing effect of a stiff-legged fall.

It would be interesting from a biophysical point of view to calculate the velocity and inertia of these accelerated landings, in order to formulate some values for the stress tolerance of the human body [9]. Unfortunately, however, there are so many indeterminate factors in parachute jumping—the nature of the terrain, the vagaries of wind, oscillation, and malfunctions, as well as the skill of the jumper—that an analysis of quantitative stress is out of the question. One must be content with a qualitative recognition of the mechanisms of injury. For all clinical purposes this is enough, for it is the nature of the trauma more than the degree which determines what kind of injuries will be produced. The mechanism of injury is fundamental in the study of trauma, and it is on this basis that fractures should be classified. Such a classification transcends the accidents of circumstance, simplifies the innumerable variations of pattern, and provides the key to intelligent treatment.

SUMMARY

1. This survey describes a series of 3,000 fractures and major soft-tissue injuries resulting from parachute jumping, with particular reference to the traumatic mechanisms involved.

2. Almost all injuries involve weight-bearing structures. The distribution and patterns of injury are generally similar to those encountered in civilian orthopaedic practice; yet there are certain minor statistical differences which are related to the peculiar stresses of parachute jumping. No injury is specific enough to be called a typical parachute lesion.

3. Almost all the injuries of parachute jumping can be attributed to four basic traumatic mechanisms:

(a) Torsion plus landing thrust. This is by far the most common mechanism of injury and is responsible for a chain of related injuries, extending from the toes to the hip.

(b) Backward landing. Vertebral compression fractures and head injuries characterize this mechanism of injury.

(c) "Opening shock" is a mechanism of injury peculiar to parachute jumping. The violent abduction stress causes many ligamentous tears and even fractures of the extremities.

(d) Violent vertical landings. Occasional parachute malfunctions increase the landing impact and cause severe multiple fractures of the legs and spine.

4. One-half of all parachute fractures involve the ankle mortise. Various authors report essentially the same statistical distribution of fractures as in the present study, although the source of the patients and the circumstances of injury are all different. The most prevalent mechanism of injury is external rotation which, together with abduction, accounts for approximately 75 per cent. of fractures at the ankle.

5. The entire lower extremity shows a preponderance of external-rotation injuries. This would imply a structural weakness of the limb as a whole,—a lack of adaptive resiliency to the stress of external torsion.

6. A classification of fractures based on etiological stresses is much more reasonable and useful than one based on anatomical location. Recognition of the etiological stresses not only relates apparently dissimilar fracture patterns, but also provides a rational approach to treatment.

NOTE: The authors wish to express their appreciation to Bernard Ryan, M.D., and to Captain Darwin Kitch, U. S. Army, for technical advice in the preparation of this paper: and also to Mr. Erich Layer, who, while a prisoner of war, made the drawings for Figures 2, 15, and 16.

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STYLOIDECTOMY OF THE RADIUS IN THE SURGICAL TREATMENT 0 NON-UNION OF THE CARPAL NAVICULAR

A Preliminary Report *

BY LEONARD BARNARD, M.D., OAKLAND, CALIFORNIA, AND SAM G. STUBBINS, M.D., CLEVELAND, OHIO

During the past two decades the diagnosis and treatment of recent fractures of th carpal navicular have been freely discussed and, in large degree, standardization of man agement has resulted. Unfortunately, this is not true of the large group of patients wh present non-union when first seen. For the treatment of this latter condition, there ai advocates of excision of the bone, bone-grafting, and wrist fusion [4,7]. Böhler states that h has never seen a normally functioning wrist after complete excision of the navicular; th authors agree with him in condemning this approach to the problem, although admittin that small fragments should be excised. Wrist fusion has its place, but it should be reserve for the very severe cases of late arthritis. The more recent reports [5,8] show the tren definitely and logically toward bone-grafting as the best solution. The type of bone-graftin preferred is an autogenous implant through a drill hole or holes. The older method o treatment by drilling resulted in too many failures and has been largely abandoned.

Fig. 1

Note the marked degenerative changes about the styloid process of the radius in this case of old ununited fracture of the navicular.

The role of the styloid process of the radius in fractures of the carpal navicular ha been given attention by a few authors. Schnek pointed out that a large styloid proces predisposes to this fracture. Others feel that the process acts as a fulcrum, over which th waist of the navicular is compressed when it receives the force producing fracture. Pro nounced degenerative arthritic changes about the radial styloid are commonly observed ii old cases of non-union of this bone (Fig. 1). This we believe to be the result of increase strain thrown upon the radial collateral ligament of the wrist at its styloid attachment plus the trauma of abnormal movement of the distal fragment against the process when i

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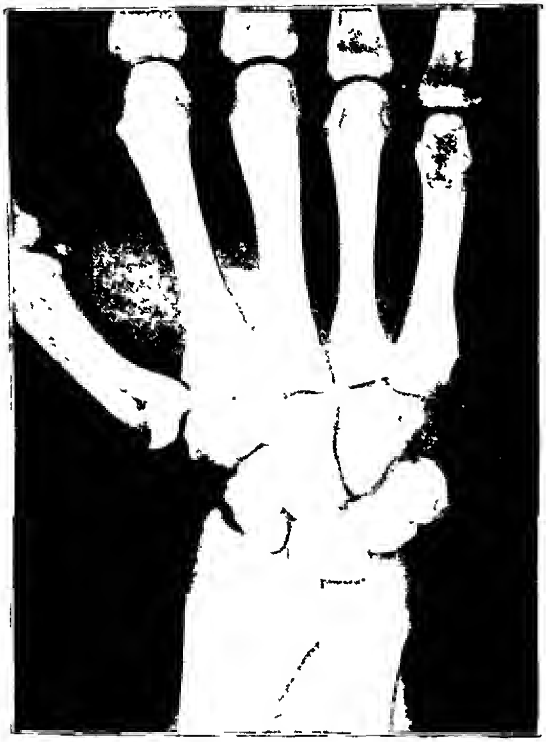

FIG. 2-A

FIG. 2-B

Fig. 2-A: F. D. This patient had a malunited navicular, which impinged against the radial styloid on flexion of the radius, limiting motion and causing pain. Preoperative film shows the malunion, with definite impingement of the navicular against the styloid

Fig. 2-B: After removal of the styloid, both the motion and the symptoms were definitely improved.

Fig. 3: Schematic drawing of procedure. The styloid process is excised and used for indwelling graft.

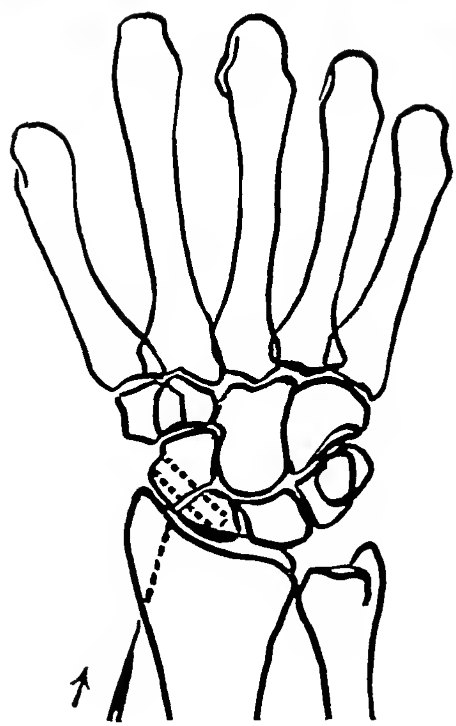

FIG 3

moves with the distal row rather than with the proximal row of carpal bones.

In radial flexion of the wrist joint, the navicular slides ulnarward along the slanted concave surface of the distal end of the radius. In so moving, it tilts anteriorly on its long axis, so that the tuberosity of the navicular moves anterior to the radial styloid. Slight motion of the wrist in the presence of fractures of the navicular waist causes the two fragments to move independently of each other. The distal fragment butts against the styloid of the radius, moving more with the distal row of carpal bones; while the proximal fragment, being adherent through the capsule to the lunate, moves in a different plane with the proximal row of carpals. This mechanism produces a shearing stress at the fracture line, and is as large a factor in non-union as the known avascularity of this bone.

The observation that a normally functioning wrist joint followed wounds which caused avulsion of the radial styloid, as well as the finding of marked displacement of the

process without discomfort in fractures, led to the consideration of sacrificing it surgically. The authors' first case (Figs. 2-A and 2-B) was one of a malunited navicular with definite

Fig. 4-A

Fig. 4-B

Fig. 4-A: J. H. Patient sustained fracture of navicular in a fall in August 1942. Bone-pegging and radial styloidectomy were carried out in September 1945. The patient was immobilized in a circular plaster for eight months before solid bony union took place. Film shows wrist before operation.

Fig. 4-B: Postoperative roentgenogram, showing result of minimum styloidectomy. Cortical bone from the tibia was used to form the bone peg employed in fixation.

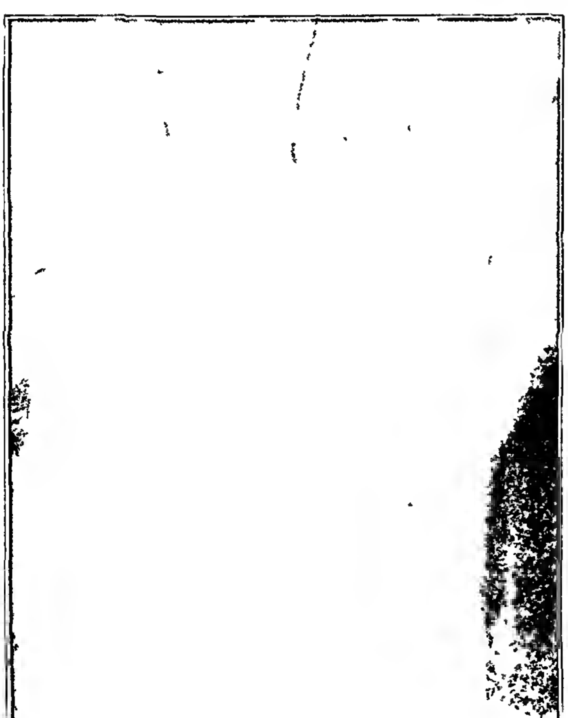

Fig. 5-A

Fig. 5-B

Fig. 5-A: E. S. Preoperative roentgenogram of patient who fractured his carpal navicular in a boxing match in 1941.

Fig. 5-B: Radial styloidectomy and bone-pegging were done in June 1946. Patient was immobilized in skin plaster for three months after operation. Roentgenogram shows evidence of solid bony union. Cancellous bone from the radial styloid was used for the graft.

mpingement against the process; removal of the radial styloid alleviated the symptoms. Hope of being able to release some of the shearing stress at the fracture site and of preventing secondary arthritic changes led to the development of the operative procedure described here (Fig. 3).

OPERATIVE TECHNIQUE

With the wrist held by an assistant in mid-pronation and ulnar deviation, the operative approach is made, after the technique of Burnett, through the anatomical snuffbox. with a three-centimeter incision directly over the radial styloid, between the extensor pollicis longus and the abductor pollicis brevis. Before operation, care should be taken to locate the radial artery as it courses dorsally; this is assured by palpation of its pulse, as its position was found to vary markedly. If the radial artery turned obliquely across the snuffbox it could be more readily retracted posteriorly, along with the superficial branch of the radial nerve and the extensor pollicis longus. More commonly it can be retracted anteriorly, with the abductor pollicis brevis and extensor pollicis brevis. The periosteum over the styloid process is then incised in the long axis, together with the capsule of the wrist joint, which at this point is largely the radial collateral ligament. The process is then freed subperiosteally of all soft tissue and removed with an osteotome.

The method of removal depends upon whether or not the styloid process is to be used for the carpal graft. If the bone is to be used in grafting, the incision should start 1.5 centimeters up the radial shaft, in order to secure a sufficiently large fragment to be reshaped for this purpose. Upon removal of the process, the navicular will be found to lie directly in the wound; and in most instances the fracture will be visible. The tuberosity can then be exposed easily, with avoidance of its dorsal arterial supply; a drill can be carried across the fracture line under visual control; and the graft can be inserted in the routine manner. The authors preferred using the removed fragment of styloid for the graft, because it could be obtained in the same field; since it was largely cancellous bone with a thin cortex, it was ideally suited for this purpose. Interestingly, the articular cartilage over the distal end of the radius does not extend up onto the styloid process. The wound is closed in layers, the radial collateral ligament being sutured over the raw bony surface of the radius. A plaster-of-Paris cylinder is applied, with the wrist in moderate dorsiflexion and the thumb included in functional position.

RESULTS

To date the authors have performed fourteen such operations, extending over a period of two and one-half years. The end results of ten are available. Union was obtained in nine, both clinically and by roentgenogram, and the functional results were good. The time interval after operation varied from three to seven months. The procedure failed in one case because the proximal fragment was too small. In this case, grafting was not justified: the small proximal fragment should have been excised. Two of these cases were done with tibial grafts, and in seven instances the styloid was used. In addition, simple styloidectomy for a malunited navicular has been performed in three cases, with excellent results. No appreciable instability of the wrist joint has been noted in any of the cases in which the radial styloid was removed.

CONCLUSIONS

The surgical removal of the radial styloid process is presented as an aid in the treatment of malunited and ununited fractures of the carpal navicular. It is believed to simplify the surgical approach, and ensures better visualization and immobilization of the fracture fragments, as well as less likelihood of secondary degenerative arthritic changes. By employing the excised styloid fragment for grafting material, the whole operative procedure can be confined to a single operative field.

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DISCUSSION

Dr. Ralph Soto-Hall, San Francisco, California: The large number and the wide variety of operations which have been suggested for the treatment of this condition reflect well the difficulty in solving this problem. I believe that the authors have contributed a valuable idea to the surgical treatment of non-union of the carpal scaphoid. However, as in all new procedures, the problem is to determine accurately the type of case for which the operation is suitable.

Non-union of the scaphoid is complex, because of the variety of pathological changes which may be associated with it; and the degree and the severity of these changes must determine our choice of treatment.

I agree with the authors that drilling should be discarded, and also that ununited fractures of the proximal pole give excellent function when treated by removal of the small fragment. On the other hand, total excision of the scaphoid gives a poor result early and a worse one later. I have followed several patients with total excision for a number of years and have noted a considerable shifting in the relationship of the carpal bones,—which explains the progressive increase in symptoms. In early cases without anatomical change, a simple bone graft answers our problem in over 90 per cent. of the cases.

In non-union of long standing we often find a mechanical arthritis of severe degree, with disappearance of the articular cartilage between the scaphoid and the radius, hypertrophy of the radial styloid, and an important, but often overlooked, subluxation or tilting of the lunate.

When these changes are severe, simple grafting or styloidectomy will not correct the disability. In these patients, particularly those engaged in manual labor, a radiocarpal arthrodesis will give a sound, painless wrist. This procedure I still believe to be the most effective one when the fundamental mechanics of the wrist have been deranged.

Total excision of the proximal carpal row is another procedure which is applicable in the late cases; but it has limited use, because too often there is residual pain and weakness.

It seems, therefore, that a fairly large number of moderately old cases of non-union exist with not too advanced deformity, which should be ideally suited for a more conservative procedure, such as that described. I have not performed this operation on the living but, after reading the authors' paper, I experimented on the cadaver. I was able to confirm the authors' clinical findings that styloidectomy does not produce instability of the wrist and that it does reduce the strain and movement at the site of the experimentally produced fracture. The approach is simple and the exposure obtained is excellent.

I want to congratulate the authors for presenting a procedure which, although not a cure-all, will, I believe, in well-chosen cases, become a permanent help in this type of surgery.

Dr. Leonard Barnard (closing): I wish to thank Dr. Soto-Hall for his kind remarks. I have one comment to make. While Dr. Soto-Hall recognizes that in early cases, without arthritic changes, simple bone-grafting gives a large proportion of good results, we see few of these cases early.

DISTURBANCE OF LONGITUDINAL GROWTH ASSOCIATED WITH PROLONGED DISABILITY OF THE LOWER EXTREMITY *†

BY DONALD ROSS, M.D., CHICAGO, ILLINOIS

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Impaired function of an extremity during its longitudinal growth may result in a discrepancy of limb length. Paralysis, skeletal infection, trauma, and congenital anomalies are among the common causes of impaired function. In such cases, the inequality of limb length is the result of growth retardation and does not entail premature closure of epiphyseal cartilage.

In some patients, however, marked length discrepancy or alignment deformity develops; and in these cases, premature closure of one or more epiphyseal discs can usually be demonstrated. These growth arrests occur in patients who have had prolonged disability of an extremity. They are not due to destruction of epiphyseal cartilage by involvement with the primary disease, but are the late consequences of deranged limb function.

This paper is concerned with premature closure of the growth cartilages at the knee in those patients who have had prolonged dysfunction of the lower limb. It is based on the study of thirteen patients, nine of whom had tuberculosis of the hip. Each of the others had pyogenic arthritis of the hip, slipped capital femoral epiphysis, poliomyelitis, or osteomyelitis of the shaft of the femur. Six patients were boys; seven were girls.

The frequency of this complication is difficult to estimate, because its recognition requires observation of the patient during several years of growth. Nine cases with growth arrest at the knee were found in a group of ninety-two patients with tuberculosis of the hip. This incidence of 10 per cent. suggests that, after tuberculosis of the hip, growth arrest at the knee is more frequent than the literature indicates. Gill's report of fifteen patients in whom this complication developed stands alone in the literature.

In the cases here recorded, the site of the growth arrest at the knee varies. In five patients, growth arrest occurred in both the distal femoral and proximal tibial epiphyseal plates. Premature closure of the distal femoral disc occurred centrally in all five; but, in the tibial disc, it occurred peripherally in four, centrally twice. (One patient had bilateral tuberculosis of the hip, and growth arrest at both knees developed.) In eight patients growth arrest of the proximal tibial epiphyseal cartilage alone developed. In this group, peripheral fusion of the plate occurred six times and central fusion twice. Seven of the peripheral arrests occurred in the posterior medial quadrant and three in the anterior quadrant of the tibial plate. The proximal fibular disc was not affected in any case.

CASE REPORTS

CASE 1. T. M., a boy, aged five, had had advanced, untreated tuberculosis of the right hip for three years. Immobilization of the hip for four months preceded arthrodesis with a tibial transplant. This was followed by immobilization for two years and ten months. Two years later, flexion-adduction deformity of the right femur was corrected by subtrochanteric osteotomy. Plaster fixation for two months was necessary after this operation. The total period of immobilization of the left lower extremity was three years and four months.

Growth arrest occurred in both major epiphyseal cartilaginous discs at the right knee. It developed first in the distal end of the femur, where there was evidence of growth disturbance two and one-half years before bony fusion of the epiphysis and the metaphysis was apparent. A roentgenogram (Fig. 1-A) of the right knee, taken upon entry, showed osteoporosis, but no abnormality of the growth cartilages. After two

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Fig. 1-A

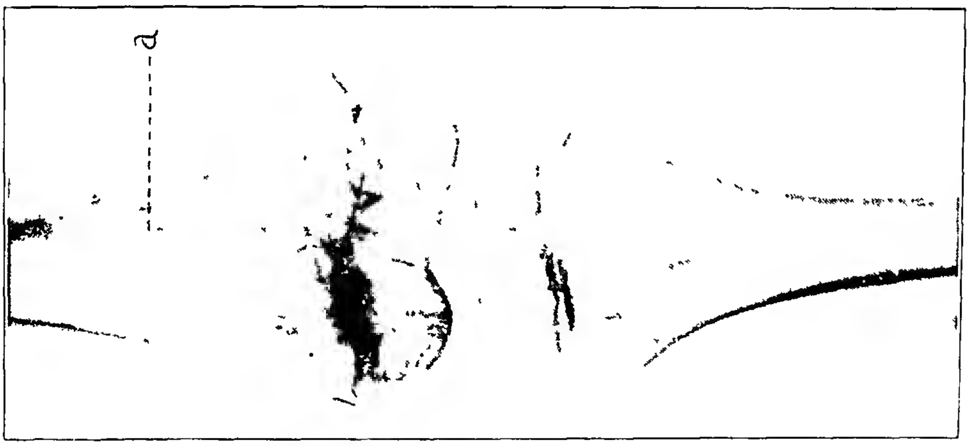

Fig. 1-B

Fig. 1-C

Case 1, T. M. Roentgenograms of knee.
Fig. 1-A: At the age of five, showing osteoporosis, but no abnormality of the epiphyseal discs.
Fig. 1-B: At the age of seven and one-half, showing thinned distal femoral plate and a radiolucent defect (*a*) in distal femoral metaphysis.
Fig. 1-C: At the age of ten, showing fusion of the central portion of the distal femoral disc and of the medial portion of the proximal tibial plate. There is posterior rotation of the femoral condyles and proximal overgrowth of the head of the fibula.

and one-half years of immobilization, a roentgenogram (Fig. 1-B) showed more marked osteoporosis, a thinned and irregular distal femoral disc, and a circumscribed area of rarefaction in the adjacent metaphysis. The growth cartilages of the tibia and fibula appeared normal. At the age of ten, one year after removal of plaster fixation, roentgenograms (Fig. 1-C) showed central closure of approximately two thirds of the distal femoral disc. Less extensive closure was present in the medial portion of the proximal tibial plate. Proximal overgrowth of the fibula was present. In both the femur and the tibia, the location of the growth arrest was eccentric and had resulted in posterior rotation of the condyles of the femur and flexion of the shaft of the tibia. The area of rarefaction in the metaphysis was no longer evident. Inequality of limb length at this time was ten centimeters; seven and five-tenths centimeters of this shortening was in the femur and two and five-tenths centimeters in the tibia.

Case 2. J. S., a boy, aged two and one-half, had tuberculosis of the right hip. Growth arrest in the central portion of the proximal tibial cartilaginous plate developed. Although the distal femoral plate ceased its longitudinal growth, it did not undergo premature ossification. Following immobilization of the extremity in plaster for sixteen months, an arthrodesis of the hip was performed. Further immobilization was carried out for fifteen months. Bony ankylosis of the hip was present at the age of five. Five years later, there was seven and five-tenths centimeters of shortening of the right lower extremity. Prominence of the head of the right fibula was noted. A roentgenogram (Fig. 2-A) demonstrated bony bridging of the proximal tibial plate at its center. There was also proximal displacement of the head of the fibula. The distal femoral disc appeared normal, but there was an irregular radiolucent defect in the distal femoral metaphysis adjacent to the center of the growth cartilage. Osteotomy of the proximal end of the tibia, with excision of most of the epiphyseal cartilage, was done in order to correct the deformity of the right knee. The prominent head of the right fibula was also removed. A roentgenogram (Fig. 2-B), taken two years later, showed that the proximal tibial epiphyseal plate had closed. The distal femoral epiphyseal plate was still open, but its relationship to the metaphyseal defect had not changed, indicating that longitudinal growth from it had ceased.

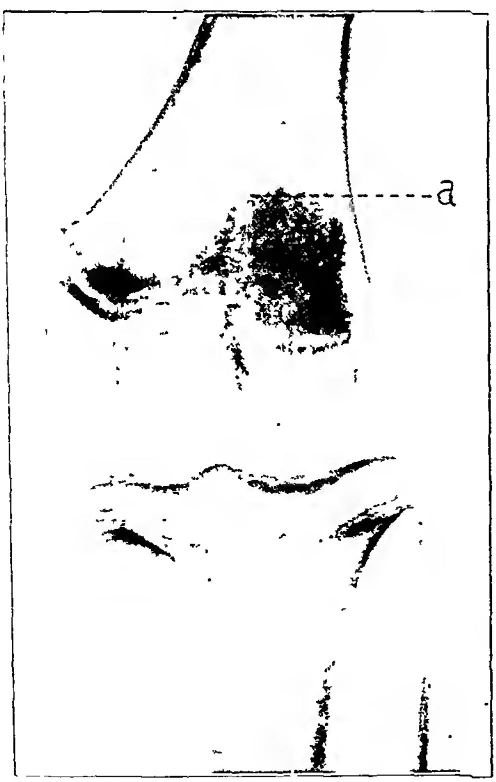

Fig. 2-A

Fig. 2-B

Case 2, J. S. Roentgenograms of knee.

Fig. 2-A: At the age of ten, showing bony fusion centrally of proximal tibial plate, proximal displacement of head of fibula, and a radiolucent defect (*a*) in the distal femoral metaphysis. (Roentgenogram has been reversed.)

Fig. 2-B: At the age of twelve, showing that the radiolucent defect has not been displaced or elongated. More extensive bony fusion of the proximal tibial disc is present. (Roentgenogram has been reversed.)

The inequality between the lengths of the femora was two centimeters and between the tibiae was fiv centimeters.

Microscopic sections of the tibial and fibular epiphyseal discs, removed at the time of osteotomy, ar shown in Figures 2-C, 2-D, and 2-E. Fibrillation and fissuring of the matrix was present and the cartilage

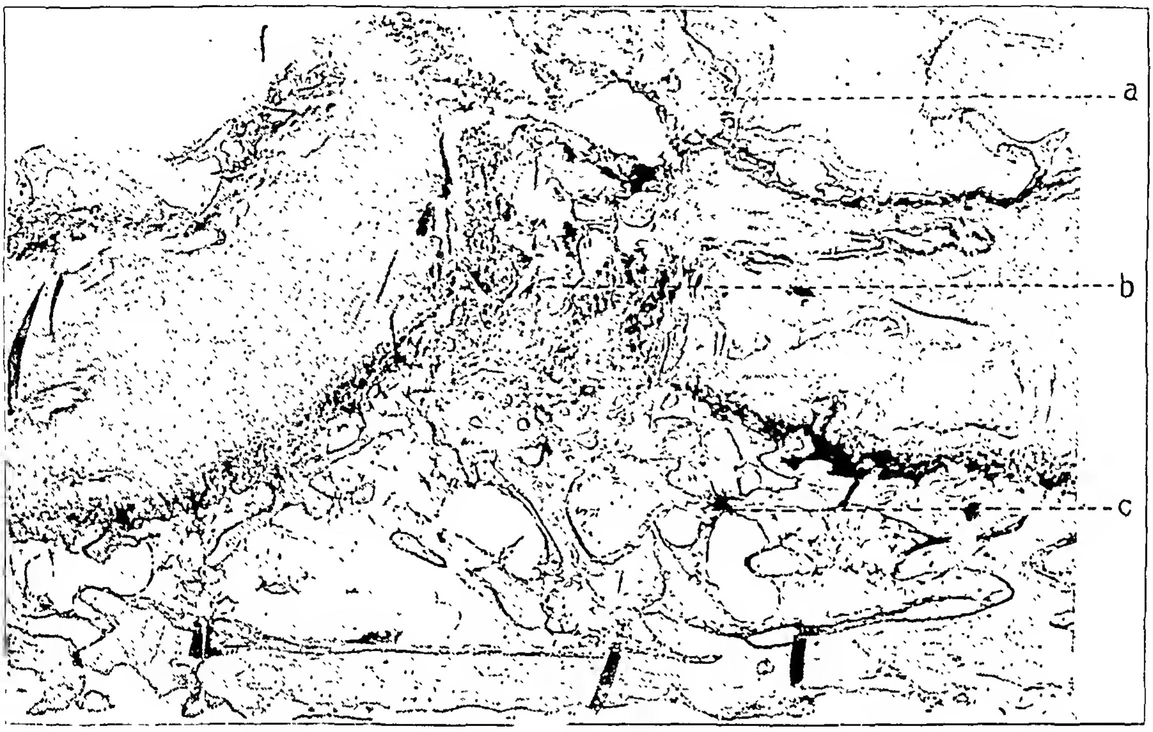

Fig. 2-C

Photomicrograph (×15) of central portion of proximal tibial plate, showing fibrous tissue and bone (*b*) uniting epiphysis (*a*) to metaphysis (*c*).

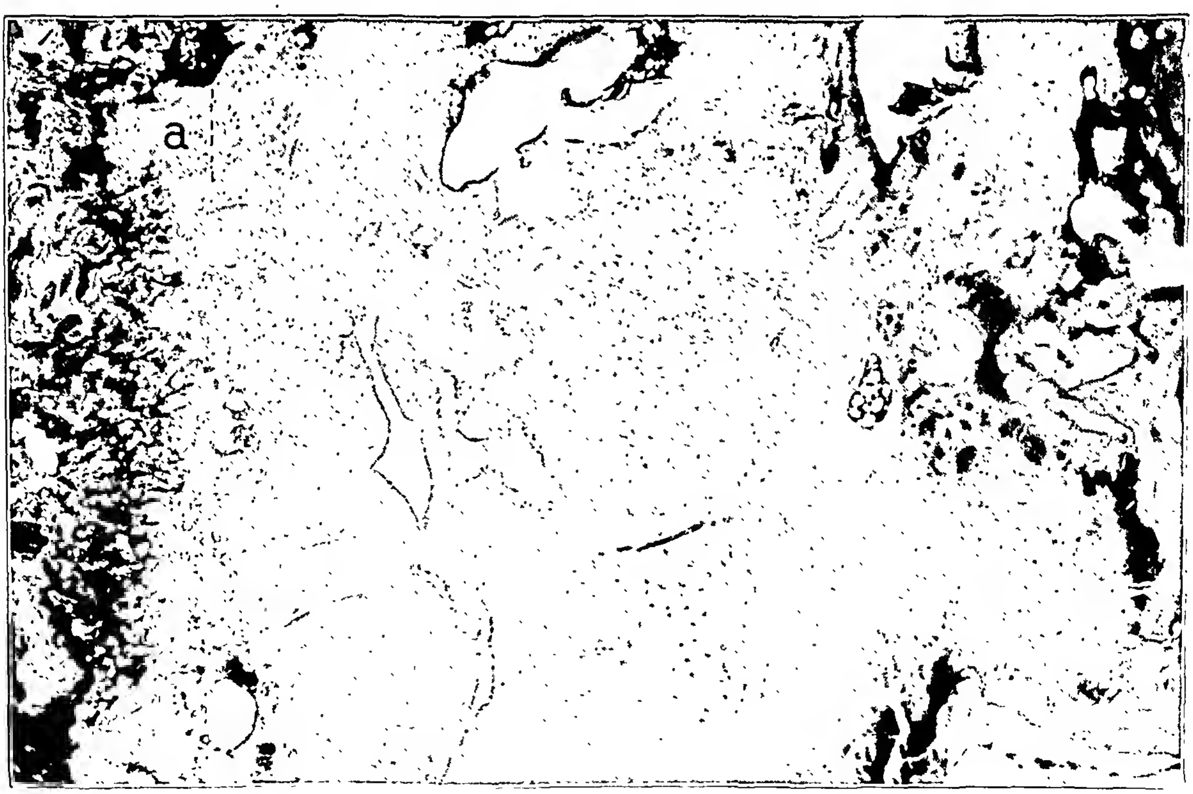

Fig. 2-D

Photomicrograph (×100). Peripheral portion of proximal tibial plate, showing fibrillation and fissuring of cartilage matrix. The cartilage-cell columns (*a*) are disorientated and shorter than normal.

cell columns of the tibial cartilaginous disc were disorientated. The fibular epiphyseal cartilage appeared normal.

When the area of arrest of a plate is eccentric, the unaffected portion continues to grow and will cause recurrence of alignment deformity unless corrective osteotomy is accompanied by surgical completion of the growth arrest. The following patient had two recurrences of tibia vara because this was not recognized.

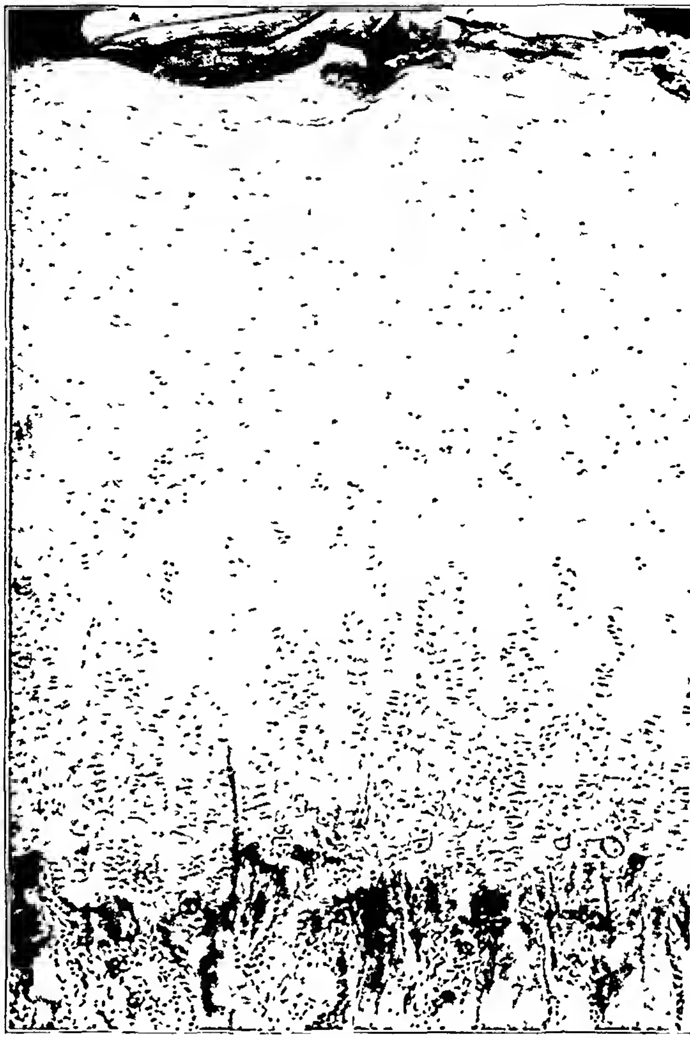

Fig. 2-E

Photomicrograph (×100). Proximal fibular epiphyseal plate is normal.

Case 3. H. B., a girl, aged ten, had had tuberculosis of the left hip since the age of two and one-half. Intermittent immobilization of the left lower extremity had been carried out for three years during the period of three and one-half to seven and one-half years of age. At entry, a varus deformity of the left knee was present. There was ten centimeters of inequality in limb length, due, in part, to a pathological dislocation of the left hip. A roentgenogram of the knee upon admission demonstrated complete bony fusion of the distal femoral cartilaginous disc and partial bony union of the medial portion of the proximal tibial plate to the metaphysis. The lateral portion of the epiphyseal plate was open, and its continued growth was indicated by the fact that there was no proximal overgrowth of the head of the fibula. The tibia vara was corrected by wedge osteotomy through the proximal tibial metaphysis. Failure to complete the growth arrest of the tibial plate resulted in recurrence of the tibia vara two years later. A second osteotomy was performed through the proximal tibial metaphysis. Again, failure to complete the growth arrest resulted in recurrence of the deformity. At the age of twenty, tibia vara of the left knee and inequality of limb length of seventeen centimeters were present.

Case 4 demonstrates the relationship of growth retardation and growth arrest to prolonged disability of the lower extremity.

Case 4. D. P., a girl, aged twelve, had pyogenic osteomyelitis of the distal two thirds of the shaft of the right femur.

A roentgenogram (Fig. 3-A), at the age of two, showed osteomyelitis and a pathological fracture of the shaft of the femur. Osteoporosis of the femur and tibia was present, but the growth discs appeared normal. At the age of four, a roentgenogram (Fig. 3-B) showed the following changes of both the distal femoral and proximal tibial discs, which indicated growth retardation: The femoral plate rose to a peak in the center of the metaphysis, the tibial disc showed a less well-developed central peak, and the head of the fibula was displaced proximally by its more rapid growth. Osteoporosis was not pronounced, because the patient had been ambulatory. Growth-arrest lines were present in the distal femoral and proximal tibial epiphyses. Six years later, at the age of ten, a roentgenogram of the knee revealed that both the femoral and tibial epiphyseal plates were still open. At the age of eleven, a roentgenogram (Fig. 3-C) showed the beginning of a bony bridging of the proximal tibial disc. The distal femoral plate was still open, and its contour was more evenly

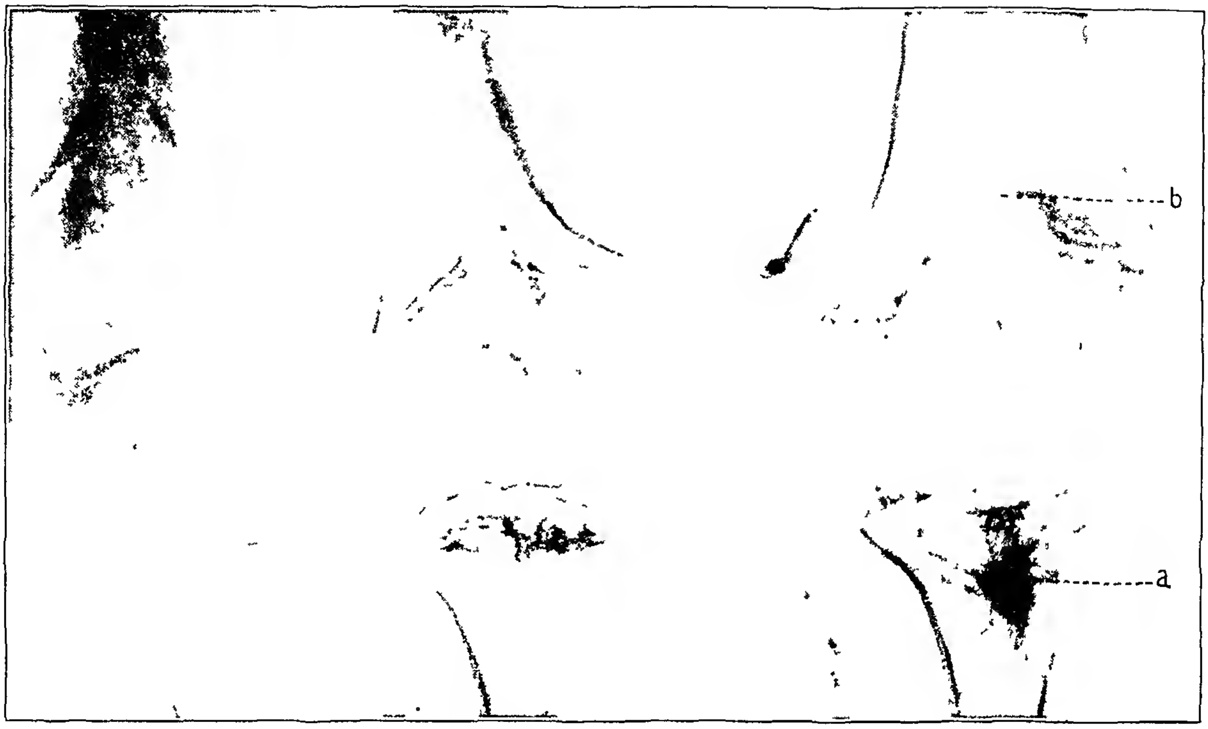

FIG. 3-A FIG. 3-B FIG. 3-C

Case 4, D. P. Roentgenograms of the knee.

Fig. 3-A: At the age of two, showing osteomyelitis of shaft of femur, but normal epiphyseal cartilages.

Fig. 3-B: At the age of four, showing healed osteomyelitis of the shaft of the femur. A central peak in the distal femoral plate and proximal displacement of the head of the fibula indicate growth retardation of the distal femoral and proximal tibial epiphyseal discs.

Fig. 3-C: A roentgenogram, at the age of eleven, showing bony bridging (*a*) of the proximal tibial plate. The central peak of the distal femoral disc now appears as a radiolucent defect (*b*).

horizontal. A radiolucent defect was present in the metaphysis of the femur in the area previously occupied by the central peak of the growth disc. The inequality of the length of the limbs at the age of eleven was six centimeters,—much less than might be expected by a growth arrest occurring near the age of two and secondary to osteomyelitis. The flexion deformity of the right tibia was corrected by osteotomy and the limb-length inequality by shortening of the left femur.

CASE 5. M. J., a girl, had tuberculosis of both hips, and growth arrest of the major epiphyseal discs of both knees developed. Onset of tuberculosis in the left hip was at the age of six, and in the right hip, at the age of seven. Arthrodesis of the left hip was performed at the age of seven. The right hip was not operated upon. Immobilization of both lower extremities in plaster dressings was carried out between the ages of six and nine and one-half. At the age of ten, six months after resumption of weight-bearing, a varus deformity of the left knee was present. Roentgenograms showed angulation of the shaft of the tibia, with proximal overgrowth of the head of the fibula. Both the distal femoral and proximal tibial plates were thin and irregular, although neither was closed. The varus deformity of the shaft of the tibia was corrected by osteotomy of the proximal metaphysis.

Bony ankylosis of the right hip did not occur. At the age of eleven, roentgenograms of the right knee showed thinness and irregularity of both the distal femoral and proximal tibial cartilaginous plates, with bony bridging of the posterior medial quadrant of the proximal tibial plate.

In the following four patients, growth arrest of the proximal tibial epiphyseal plate developed. In each case, the bony bridge was located in the posterior medial quadrant of the cartilaginous disc.

CASE 6. P. O., a girl, aged two, had had tuberculosis of the right hip for nine months. There was a persistently draining sinus. The extremity was immobilized in plaster dressings for four and one-half years. At the age of six and one-half, arthrodesis of the right hip was performed. Further immobilization of the hip in plaster was carried out for one and one-half years. Motion was still present in the hip when immobilization was discontinued. Bony ankylosis of the hip was present one year later, but there was also marked flexion adduction of the femur.

One year after the patient resumed weight-bearing, roentgenograms of the right knee showed closure of the proximal tibial epiphyseal cartilage medially and posteriorly. No alignment deformity of the tibia was present, but the head of the fibula had overgrown proximally. The distal femoral epiphyseal plate was

open, but the disc showed irregularity in its medial portion. Roentgenograms two years later showed flexion and varus deformity of the shaft of the tibia. The bony bridging of the tibial disc was wider. The irregularity, previously noted in the medial half of the distal femoral plate, had disappeared, but longitudinal striations of dense trabeculae were present in this region. Osteotomy to correct the deformity of the tibia was done through the proximal tibial metaphysis. During this operation, the proximal end of the tibia was inspected and no evidence of epiphyseal cartilage was found. The deformity of the tibia did not recur, nor did the distal femoral epiphyseal plate undergo premature closure.

CASE 7. J. G., a boy, aged nine, had had tuberculosis of the left hip for nine months. Operation to produce ankylosis of the hip was done at the age of nine and was repeated at the age of eleven. Plaster immobilization of the extremity was carried out for three years and three months. The patient was ambulatory on crutches, without bearing weight on the affected limb, for an additional year. Bony ankylosis of the hip was never obtained.

Prolonged immobilization was carried out in this patient during the period of rapid growth, and weight-bearing on the affected limb was not allowed until the age of thirteen and one-half. No roentgenographic examination of the knee was made prior to the time of normal epiphyseal maturation. Because of instability of the knee, however, roentgenograms were made at the age of seventeen. The results of an unequal arrest of growth in the proximal tibial plate were shown by the underdeveloped medial tibial tuberosity, the overgrowth of the head of the fibula, and an oblique growth-arrest scar in the proximal tibial metaphysis.

CASE 8. J. P., a girl, aged seventeen, had bony ankylosis of the right hip with marked flexion-adduction deformity of the femur. An alignment deformity of the right knee and a discrepancy of eleven centimeters in limb length were also present. The patient had had a draining sinus in the right hip from the age of four to eight, but she had had no motion in the joint since she was five. She had had no treatment other than several months of bed rest at the onset of the disease. The primary coxitis was assumed to have been pyogenic.

Roentgenograms (Fig. 4) of the right tibia at the age of seventeen showed marked varus and posterior angulation of the proximal metaphysis of the tibia. The lateral view showed marked anterior bowing of the shaft of the fibula and overgrowth of the head of the fibula above the level of the knee joint. The condyles of the femur were rotated posteriorly, indicating that unequal growth arrest had occurred in the distal femoral plate. That growth arrest also occurred in the distal tibial epiphyseal cartilage is indicated by the medial and posterior inclination of the distal tibial articular surface. The deformities of the right lower extremity were corrected by subtrochanteric osteotomy of the femur and multiple osteotomies of the shafts of the tibia and fibula. The inequality in limb length after the osteotomies was corrected by lengthening the right tibia four centimeters and shortening the left femur six centimeters.

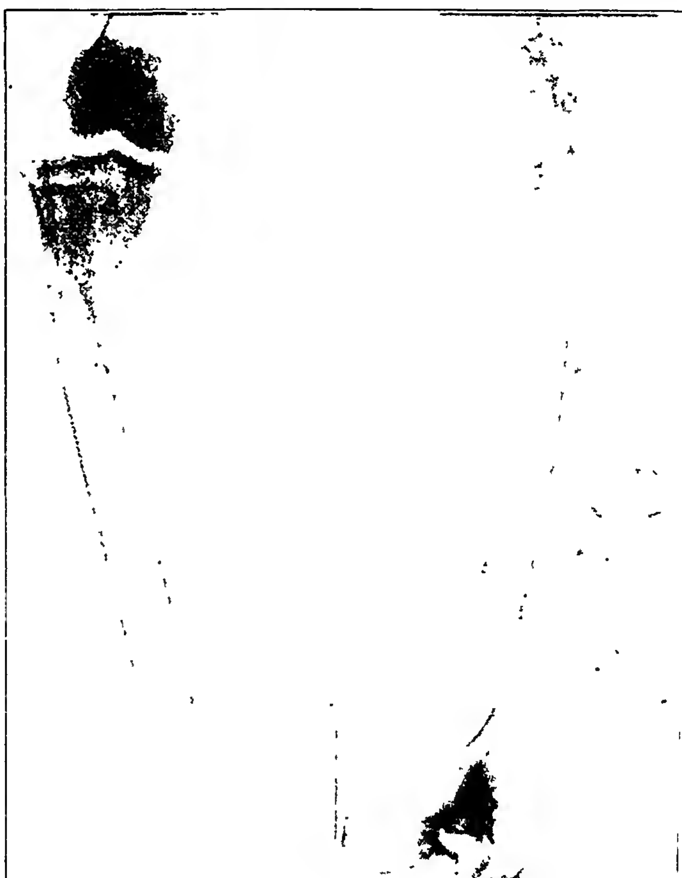

FIG. 4

Case 8, J. P. Roentgenograms of right leg, at the age of seventeen, showing varus and posterior angulation proximally in the tibia, overgrowth and bowing of the fibula, posterior rotation of the femoral condyles, and obliquity of the distal tibial articular surface.

CASE 9. M. B., a boy, had acute anterior poliomyelitis at the age of four, which affected the trunk and both lower extremities. After two

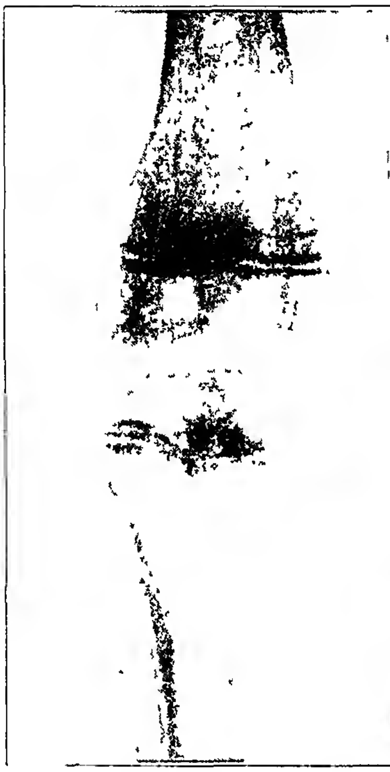

FIG. 5-A

FIG. 5-B

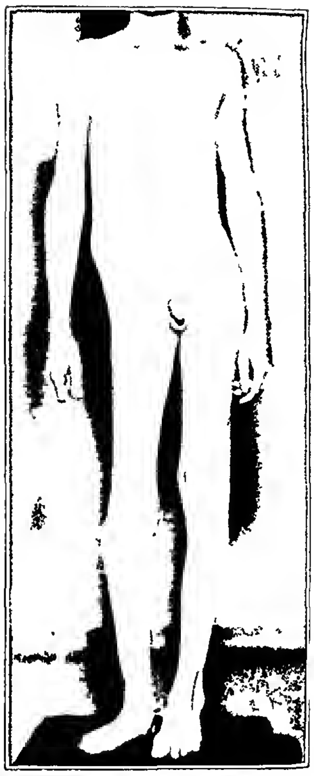

FIG. 5-C

Case 9, M. B. Roentgenograms of knee and photograph of patient.
Fig. 5-A: At the age of ten, showing bony bridging medially at the tibial cartilaginous disc. Alignment deformity of the knee has not yet developed.
Fig. 5-B: At the age of twelve; tibia vara and proximal displacement of head of fibula are now present.
Fig. 5-C: Photograph at the age of twelve, showing tibia vara and shortening of right tibia.

years, almost complete recovery had occurred in the left lower extremity, but there was residual paralysi of the right hip flexors, glutaeus medius, quadriceps femoris, biceps femoris, and calf muscles. There wa internal rotation of the tibia upon flexion of the knee, because of the unopposed pull of the medial hamstrin muscles. From the age of six t eight the right limb was supporte in a long leg brace. This was dis carded after operative stabilizatio of the foot.

At the age of ten, three centime ters of shortening of the right tibi was present. The femora were equa in length. Roentgenograms (Fig 5-A) revealed bony bridging of th posterior medial quadrant of th proximal tibial epiphyseal plate Proximal overgrowth of the head o the fibula was evident. An obliqu growth arrest line was seen in th proximal metaphysis of the tibia Roentgenograms (Fig. 5-B) tw years later showed increased bony bridging of the tibial disc and proxi mal displacement of the head of the fibula. Photographs (Fig. 5-C) at the age of twelve showed the inequality of length between the tibiae, and a marked tibia vara deformity was then present. Some flexion of the knee was also present. The deformity was corrected by osteotomy

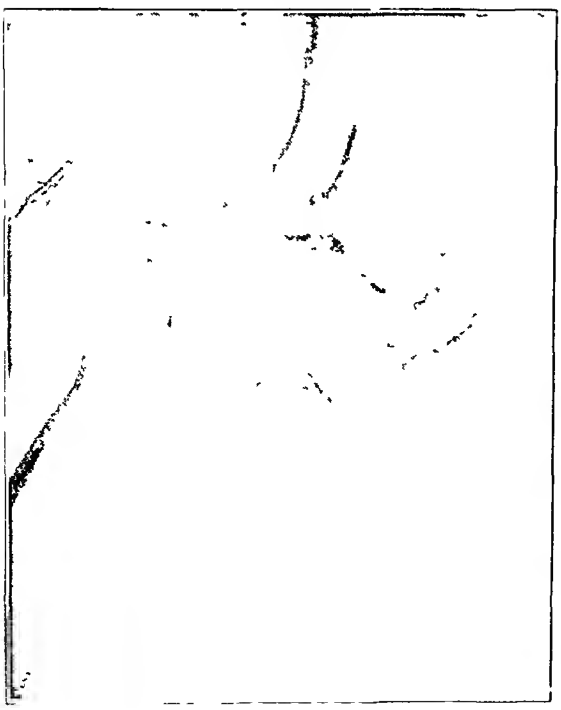

FIG. 6-A

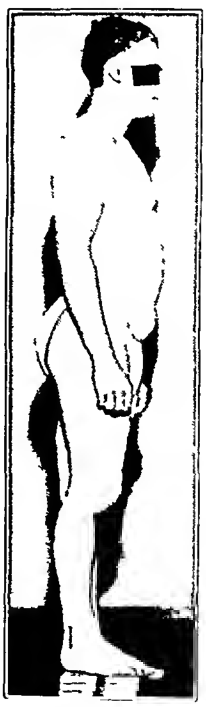

FIG. 6-B

Case 10, L. L. Lateral roentgenogram and photograph, at the age of fifteen, showing anterior angulation of shaft of tibia and genu recurvatum.

of the tibia with epiphyseodesis of the anterior lateral portion of the proximal tibial growth disc and excision of the head of the fibula. Examination at the age of fourteen showed no recurrence of the deformity.

Growth arrest occurred in this patient without prolonged immobilization of the extremity. The imbalance of muscle pull at the hip and at the knee probably was an important factor in the development of the growth deformity.

In three patients growth arrest occurred in the anterior portion of the proximal tibial plate. The disability responsible for the growth disturbance started later in childhood in these patients than in the previous cases, in which the growth arrest was located in the posterior medial quadrant of the proximal tibial disc.

CASE 10. L. L., a boy, had had tuberculosis of the right hip at the age of seven. His right lower extremity was at that time supported in a plaster dressing for seven months. One year later the right knee was manipulated under anaesthesia, because of persistent limitation of motion. A supracondylar fracture of the right femur resulted, necessitating further immobilization in plaster for three months. Soon after entry to the Hospital, at the agè of ten, arthrodesis of the right hip was done. Bony fusion followed immobilization for another nine months.

When he was thirteen, the patient noticed progressive anterior protrusion of his right patella. A roentgenogram (Fig. 6-A) of the knee at the age of fifteen showed anterior angulation of the shaft of the tibia and proximal displacement of the head of the fibula. The tibial epiphysis was fused to the metaphysis. The distal femoral and proximal fibular discs were still evident. A photograph (Fig. 6-B) at the same age showed the deformity of the right knee. The right lower extremity was ten centimeters shorter than the left. The deformity of the tibia was corrected by wedge osteotomy. The residual inequality of seven centimeters in limb length was corrected later by shortening of the left femur.

CASE 11. V. H., a girl, had had tuberculosis of the right hip since the age of seven. Arthrodesis was done at the age of eleven Flexion-adduction deformity of the right femur was corrected by a subtrochanteric osteotomy at the age of thirteen. The total period of immobilization in plaster dressings was one year and eleven months. No deformity of the right knee was noted when the patient was discharged at the age of thirteen.

FIG. 7-A FIG. 7-B

Case 12, J. B. Roentgenograms of knee.
Fig. 7-A: At the age of twelve, showing bony bridging (*a*) of anterior aspect of proximal tibial plate.
Fig. 7-B: At the age of fourteen, showing anterior angulation of shaft of tibia

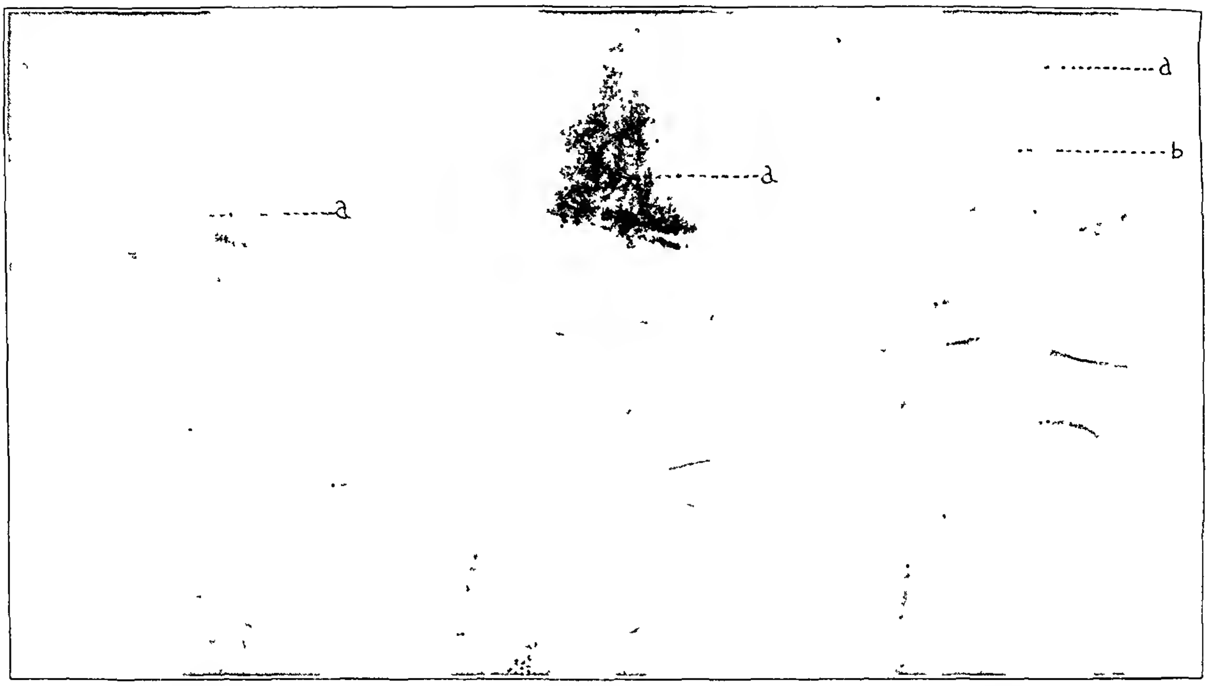

FIG. 8-A FIG. 8-B FIG. 8-C

Case 13, R. Z.
Fig. 8-A: Roentgenogram of knee, at the age of seven, shows irregularity (*a*) of distal femoral plate present after three years' fixation in a plaster dressing.
Fig. 8-B: At the age of eight and one-half, showing this irregularity separating from epiphyseal disc after weight-bearing had been resumed.
Fig. 8-C: At the age of ten, showing radiolucent defect (*a*) left behind in the metaphysis with continued growth; a second defect (*b*) was seen adjacent to the growth cartilage.

Examination at the age of twenty-six showed a marked recurvatum deformity of the right tibia. The patient did not remember the onset of the deformity. Roentgenograms of the right knee showed anterior angulation of the shaft of the tibia and proximal displacement of the head of the fibula.

CASE 12. J. B., a boy, aged eleven, had a marked slipping of the right capital epiphysis of the femur for which he had been immobilized in plaster for seven and one-half months. Roentgenograms of the knee (Fig. 7-A), taken at the age of twelve, three months after the plaster dressing had been discontinued, showed bony fusion anteriorly of the proximal tibial plate to the metaphysis. A roentgenogram (Fig. 7-B), taken two years later, showed the anterior angulation of the shaft of the tibia which resulted. This deformity was corrected by osteotomy.

The following case demonstrates the evolution of a growth irregularity of the distal femoral epiphyseal cartilage into a radiolucent defect in the distal femoral metaphysis.

CASE 13. R. Z., a girl, aged four, had tuberculosis of the left hip which had been present since the age of three. After plaster immobilization from the age of four to the age of seven, arthrodesis of the left hip was done. Immobilization for ten months followed this operation. Bony ankylosis was complete at the age of eight.

A roentgenogram of the left knee at the age of four showed osteoporosis and shadows of the epiphyseal cartilages which appeared normal. At the age of seven, after three years of immobilization, a roentgenogram (Fig. 8-A) showed evidence of marked growth disturbance at the left knee. Both major epiphyseal cartilages were thin and irregular. The width of the shaft of the tibia was markedly reduced. The subchondral zone of ossification of the distal femoral disc was sclerotic, and the plate had a central peak projecting into the metaphysis. Dense longitudinal trabeculae were present near the posterior medial quadrant of the proximal tibial disc. Premature closure of either or both of these epiphyseal discs might be expected to follow such growth disturbance. However, roentgenograms (Fig. 8-B), taken at the age of eight and one-half, after weight-bearing had been resumed, showed more nearly normal epiphyseal cartilages. No displacement of the head of the fibula was present. The peak at the center of the distal femoral disc was elongated into the metaphysis as a radiolucent defect. In the roentgenogram (Fig. 8-C), at the age of ten, both the proximal tibial and distal femoral discs were open and appeared normal. Two defects were now present in the distal femoral metaphysis,—one adjacent to the posterior aspect of the growth cartilage and another more proximal in the shaft. It may be assumed that the more proximal defect was formed first and had become separated

rom the epiphysis by longitudinal growth of the femur. At the age of fourteen, roentgenograms showed usion of all the growth cartilages. The proximal displacement of the head of the fibula and the medial anulation of the shaft of the tibia indicated that premature fusion of the proximal tibial plate had occurred luring the preceding four years.

ROENTGENOGRAPHIC APPEARANCE

Roentgenographic evidence of growth disturbance at the knee is usually present prior :o the development of marked inequality of limb length or alignment deformity. It ısually is not detected, however, because roentgenograms of the knees of these patients ıre not made until some factor, such as deformity, calls attention to the knee. By this time there are marked alterations in the epiphyseal cartilages, which represent advanced growth disturbance. The early changes are not observed unless repeated roentgenographic examinations are made from the onset of the disability to the end of the active growth period. In seven patients of this group, such serial roentgenograms were made.

The early alterations of the epiphyseal cartilage, which are evidence of growth disturbance at the knee, are thinness of the epiphyseal disc and the presence of a transverse zone of dense bone on its metaphyseal aspect. Growth-retardation scars are numerous, and osteoporosis of the regional bone is pronounced. The contour of the epiphyseal cartilage is irregular with one or more peaks projecting into the metaphysis. In some instances, radiolucent defects in the metaphysis are further evidence of deranged endochondral ossification (Cases 1, 2, 4, 6, and 13). Such changes may precede actual cessation of growth; but, in some cases, recovery of normal longitudinal growth occurs.

If growth arrest does occur, roentgenograms show a bony bridge across the epiphyseal disc. The transverse zone of bone on the metaphyseal aspect of the disc becomes wider and more dense in the region of this bony bridge, and long trabeculae converge toward its site from both the epiphysis and the metaphysis.

Certain sites are more favorable for epiphyseal bridging. In the distal end of the femur, the point of arrest is commonly posterior to the central portion of the disc. The remaining disc may continue to grow, causing posterior rotation of the condyles. In the proximal end of the tibia, the arrest is often in the posterior medial quadrant, in which case continued growth of the remaining cartilage results in tibia vara. Not infrequently, the tibial tubercle unites prematurely with its metaphysis, and tibia recurvata develops. In either case proximal displacement of the fibula in relation to the tibia occurs.

PATHOLOGICAL FINDINGS

The essential pathological change is degeneration of the epiphyseal cartilage and its replacement by bone. At the site where the plate is bridged, trabeculae of normal character unite epiphyseal and metaphyseal bone. The adjacent portions of the disc show the most marked changes and become thinned, fibrillated, and fissured. Cartilage cells are irregularly placed so that columns are short and disorientated. Transversely, orientated trabeculae cover the metaphyseal surface of the plate. Although the disc may continue some growth away from the point of bridging, its matrix and cartilage cells show some degree of degenerative change. These alterations are demonstrated in Figures 2-D and 2-E.

TREATMENT

Prevention of growth deformity in chronic diseases of the lower extremity is not always possible. However, measures that shorten the duration of disability from hip disease (such as operative fusion), avoidance of prolonged immobilization, and careful supervision of the patient who resumes weight-bearing on a limb which has undergone marked osteoporosis, may minimize the chance of growth arrest. If arrest does occur, early recognition may make it possible to avoid deformity or marked discrepancy in limb length by the employment of an epiphyseal-arrest operation. There is no way to produce resumption of normal growth from a cartilaginous disc which has undergone partial or

complete fusion. If asymmetrical growth arrest has occurred, alignment deformity must be prevented by producing surgically a complete arrest of growth in that epiphysis. Employment of the growth-arresting operation on the normal limb to produce eventual equalization of limb length depends upon the amount of shortening present and the amount anticipated when skeletal growth is complete. In patients whose skeletal growth is complete, equalization of limb length may be obtained by femoral shortening on the normal side, sometimes by lengthening of the short limb, or occasionally by a combination of both.

DISCUSSION

Atrophy of disuse accompanies any prolonged disability of an extremity, and during the growth period it affects the epiphyseal cartilage as well as the other tissues in the limb. Although osteoporosis becomes evident a short time after the onset of the disability, the epiphyseal discs appear normal in roentgenograms until the disability has been present for a prolonged period. The thinness and irregularities of the disc, and the dense transverse plate of bone which is then present on its metaphyseal aspect, give the disc an appearance similar to any epiphyseal cartilage at the time of its normal maturation. Radiolucent defects in the metaphysis and peaks of epiphyseal cartilage projecting into the metaphysis may also be present at this time. These latter changes, however, are not observed in normal closure of the epiphyses, and are difficult to explain adequately. The peaks probably represent areas of localized growth retardation in the epiphyseal cartilage, and are left behind in the metaphysis with the continued growth of the less affected portions of the plate. On the other hand, the dense transverse plate of bone which forms on the metaphyseal aspect of the cartilaginous disc with growth retardation may inhibit the circumferential increase in the size of the epiphysis, and thus cause the growing plate to buckle. The apex of these peaks would be a favorable site for the first appearance of growth arrest, but in several patients in this report (Cases 4, 6, and 13), the apex of the peaks seemed to break off and form a radiolucent defect in the metaphysis. Thus, the defect would represent an epiphyseal-cartilage rest, an unwarranted assumption without a biopsy. In Case 13, one such defect formed in the femur and was displaced into the metaphysis by longitudinal growth. A second, more distal, defect then formed. It is more likely that the defects consist of fibrous tissue. They have roentgenographic similarity to the early appearance of the lesion described by Jaffe as a non-ossifying fibroma and by Hatcher as a metaphyseal fibrous defect. The defects disappeared with subsequent growth of the bone.

Although the growth-retardation changes discussed above are more pronounced at the more rapidly growing epiphyseal plate at the distal end of the femur, actual premature closure was observed more frequently at the proximal end of the tibia. As the osteoporosis disappeared with active use of the limb, the epiphyseal discs frequently assumed a more normal appearance, and the inequality of limb length did not increase. In most patients with tuberculosis of the hip, several years elapsed between the discontinuation of plaster fixation of the extremity and the occurrence of growth arrest. These observations indicate that, while atrophy of disuse may cause partial degeneration of epiphyseal cartilage and growth retardation, it alone does not cause growth arrest.

Growth arrest occurs when the epiphysis and the metaphysis are united by a bony bridge across the epiphyseal plate. Gill had suggested that this bridge forms as a result of a rupture of the epiphyseal disc when the normal support of the disc collapses with fracture of the adjacent atrophied trabeculae. Fracture across an epiphyseal plate does frequently result in growth arrest. However, it seems unlikely that this is the only explanation of the growth arrest in these patients, since the growth arrest would be detected soon after plaster immobilization has been discontinued, while osteoporosis is most pronounced. Also, elastic cartilage resists fracture better than atrophic bone does.

An alternate explanation of the growth arrest in these cases is that the already par-

tially degenerated cartilage is unable to withstand the abnormal stresses of a faulty gait. The cartilage wears through at the point of greatest stress and allows bony union of the epiphysis and metaphysis. In favor of this is the high incidence of growth arrest in the posterior medial quadrant of the proximal tibial plate, and the fact that growth arrest never occurred in the fibula, which is unimportant in weight-bearing.

CONCLUSIONS

1. Growth arrest may occur at the knee as a complication of chronic disability of the lower extremity.

2. Growth retardation of the epiphyseal discs precedes permanent arrest. This retardation is due to partial degeneration of the cartilage as the result of atrophy of disuse.

3. Arrested growth occurs later, due to complete degeneration of a portion of the epiphyseal plate and the repair of the defect so formed by a bony bridge.

4. This complete degeneration is probably due to some secondary factor, such as the abnormal stresses present with a faulty gait.

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INTERNAL CONTACT SPLINT

DISCUSSION

(*Continued from page 52*)

of fixation and present it to this Academy, since I believe he has made a very definite contribution to the treatment of fractures by internal fixation.

DR. G. W. N. EGGERS (closing): When one has been following plate immobilization of fractures for a period of years, only a firm conviction of its failure turns one to another method, especially when this method is diametrically opposed to past teachings. The first case requires a little courage, and after that it is simplicity itself. As to the shearing force, it is decreased by the use of a long splint. Complete immobilization is not necessary in the treatment of fractures, but we should endeavor to accomplish physiological stability. I do not use a screw placed obliquely across the fragment ends, because the longitudinal muscle pull locks the fragments sufficiently to hinder rotation. It simplifies the technique to use only four screws, placed at chosen points in the fragments, instead of in the holes dictated by a plate.

HYPERMOBILE FLAT-FOOT WITH SHORT TENDO ACHILLIS *

BY COLONEL ROBERT I. HARRIS, M.C., AND MAJOR THOMAS BEATH

Royal Canadian Army Medical Corps

It may appear strange that there is any necessity to discuss such a common and apparently simple entity as flat-foot. The explanation is that the problem of pes planus is not simple, but in reality is complex and obscure. The configuration and the function of the foot are determined by the interplay of many factors. Even today, we know all too little of the nature and the mode of action of these forces. Attempts to advance our knowledge of the subject are handicapped by lack of material for the study of foot function in relation to structure. In the autopsy room, feet are not commonly the subject of study. Even in the anatomical museum, where abundant material for the study of structure is available, knowledge is lacking of function during life, to correlate with changes in structure which may be present. It is not surprising, therefore, that the accumulation of accurate knowledge regarding foot problems has been slow.

The purpose of this paper is to report certain recent observations regarding flat feet, and particularly to discuss the relationship between the architecture of the tarsus in severe flat-foot and the impairment of function resulting therefrom.

Not all feet which are flat are the cause of serious incapacity. On the other hand, great disability does arise from certain types of flat-foot. Flat feet are not all alike, either in their causation or in their deformity. Indeed, the term "flat-foot" is used somewhat loosely to describe all foot deformities characterized by lowering of the longitudinal arch. This condition may result from various causes. It becomes important, therefore, to distinguish from each other the various types of flat-foot and to determine the cause of each.

During 1944 and 1945, the Royal Canadian Army Medical Corps conducted an extensive survey into Army foot problems, which included the careful and detailed examination of the feet of 3 600 recruits, and the subsequent re-examination during training of those who enlisted. During the course of this survey, which revealed a representative cross section of the foot problems of young men, it became evident that pes planus must be divided into at least three varieties: (1) the severe and disabling type discussed in this paper; (2) peroneal spastic flat-foot, also gravely incapacitating; and (3) simple depression of the longitudinal arch. In contrast to the first two, this third type is of little consequence as a cause of disability. The low arch in such cases may be regarded as the normal contour of a strong and stable foot, rather than the result of weakness in foot structure or weakness of the muscles which motivate the foot.

We are concerned here with the severe and disabling type of flat-foot, mentioned first in the preceding paragraph. Because of clinical characteristics which will be discussed, we have applied to it the descriptive title of "hypermobile flat-foot with short tendo achillis". This new, elaborate, and somewhat cumbersome title is not intended to suggest that we are describing a new variety of flat-foot, hitherto unrecognized. It is used because it describes the chief clinical features of the syndrome, and also because it emphasizes the necessity of recognizing different types of flat feet which must be distinguished from one another. Hypermobile flat-foot with short tendo achillis ("HFF-STA") is one such variety which presents distinctive clinical features, the result of alterations in the relationship of the talus to the calcaneus.

This type of flat-foot is the common form of severe pes planus in childhood and young adult life. Many authors have recognized and described its various clinical manifestations, especially the short tendo achillis. No one, as far as we can ascertain, has appreciated it as

* Read at the Annual Meeting of The American Orthopaedic Association, Hot Springs, Virginia, June 27, 1946.

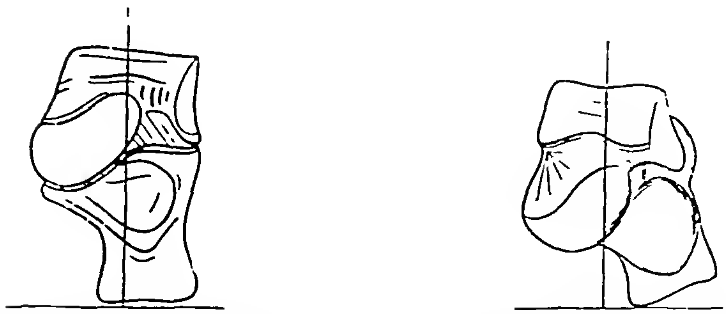

FIG. 534.—The relation of the astragalus to the os calcis.

FIG. 535.—The relation of the astragalus and os calcis in flat-foot.

FIG. 1

Diagrams illustrating Whitman's conception that, in flat-foot, the head of the talus is displaced inward and downward in relation to the calcaneus. Whitman implies that this is the *result* of the flat-foot deformity, rather than the *cause*, as is actually the case. (*Reproduced, by permission of Lea and Febiger, from* A Treatise on Orthopaedic Surgery, *by Royal Whitman, Ed. 5, 1917, p.* 694.)

a clinical entity, based upon a specific structural relationship of the talus to the calcaneus. Such new knowledge as can be contributed by this paper is related to the demonstration of this fact.

Royal Whitman described well many of the clinical features of this type of flat-foot, and illustrated with diagrams (Fig. 1) his conception of the changed relationship of the talus to the calcaneus in flat-foot. Although his conception is not based upon anatomical or roentgenographic observations and is regarded by him as the *result* of the deformity, it closely resembles the structural deviation which we have observed in our patients, and believe to be the *cause* of the deformity. Hibbs, in 1914, apparently was describing this type of foot in children, although he placed the whole emphasis upon the short tendo achillis. Certain German authors, including Schultze and Gocht, have advocated lengthening of the tendo achillis in the treatment of severe flat-foot. They seem to have been treating the type of flat-foot described in this paper, with emphasis upon the short tendo achillis.

Hoke described this type of flat-foot well in 1931, but his mistaken conception that muscle power plays the all-important role in maintaining the shape of the foot led him to the false conclusion that navicular-cuneiform fusion will most simply correct the condition by providing a longer lever through which the muscles may exert their power. By his operation, some improvement is obtained by the lengthening of the tendo achillis, but the fundamental structural weakness is unaffected. In our hands, Hoke's operation for flat-foot has been disappointing.

CLINICAL MANIFESTATIONS OF HYPERMOBILE FLAT-FOOT WITH SHORT TENDO ACHILLIS

Hypermobile flat-foot with short tendo achillis presents distinctive features which are so characteristic as to render its recognition easy in well-marked cases.

History

Since this type of flat-foot is based upon a congenital anomaly of structure of the talus and the calcaneus, the resulting deformity appears early in life. Many cases, and perhaps all, become manifest in childhood by the observation of an alert parent that there is flatness of the feet. He is the more likely to be aware of his child's deformity, since he himself may suffer from the same condition; there is a strong tendency for it to be inherited. For a varying period of time the deformity does not produce symptoms, but sooner or later appear pain and aching in the feet and fatigue on standing or walking. Symptoms may be evident as early as five years of age, but they more commonly appear

in the early teens. From the time of the first appearance of symptoms, there is a history of constant foot disability and limited capacity for foot effort. The child learns to avoid strenuous sports and heavy activities, and by this means adjusts himself to a regimen of activity which falls within the limitations imposed by his disability. The characteristic history, therefore, is one of flat-foot since childhood with some degree of incapacity

FIG. 2

Hypermobile flat-foot with short tendo achillis. The foot is not deformed unless it is bearing weight. This can best be demonstrated by seating the patient on the edge of a table and permitting his legs and feet to dangle from the knees, completely free of superimposed weight.

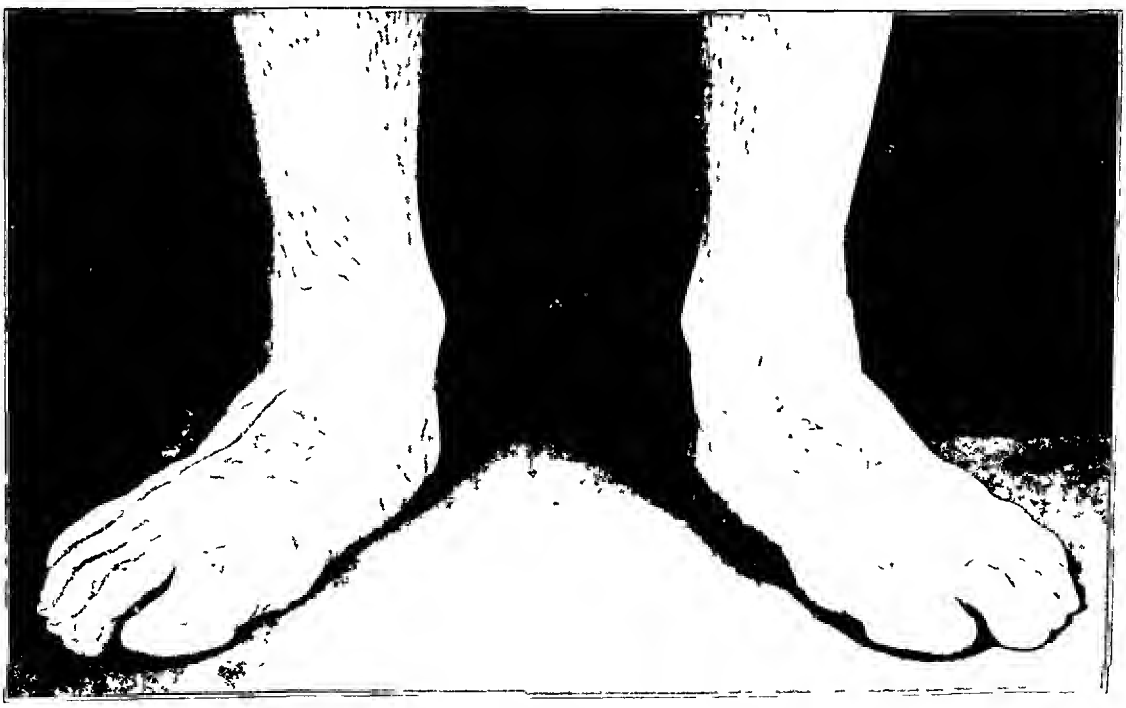

FIG. 3

Hypermobile flat-foot with short tendo achillis of moderate severity (same case as illustrated in Fig. 2). When weight is borne upon the foot, the position of well-marked flat-foot is assumed.

FIG. 4

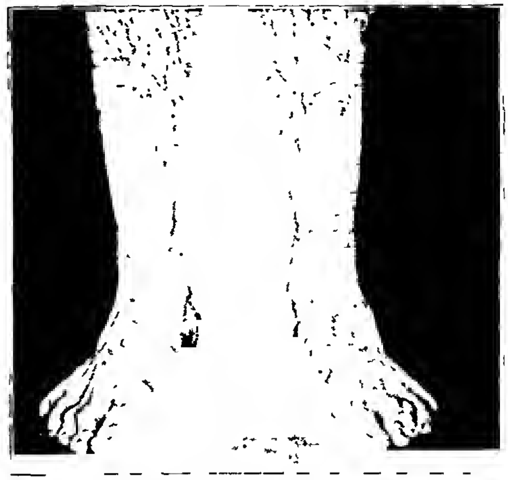

FIG. 5

Fig. 4: Hypermobile flat-foot with short tendo achillis of moderate severity (same case as illustrated in Fig. 2). The deformity can be corrected effectively by muscular effort, if the patient stands on his tiptoes.

Fig. 5: Hypermobile flat-foot with short tendo achillis of moderate severity (same case as illustrated in Fig. 2). When the patient stands with heels on the floor, the deformity can still be corrected by muscular effort, although less easily and less well. Note the use of the long toe flexors to accomplish correction.

observed first in late childhood or early adolescence and continuous and increasing since then. It should be emphasized, however, that the disability in youth usually is not so great as might be expected from the degree of flatness of the feet; also that there are wide variations in the basic abnormality and consequently wide variations in the severity of the deformity and in the degree of functional incapacity.

Feet Flat only on Weight-Bearing

In typical cases, the flatness of the feet is manifest only when the patient bears weight. When weight is completely removed from the feet, they assume a shape which seems normal (Fig. 2). When the feet are placed on the floor and weight is borne upon them, they assume a marked degree of pes planus of a characteristic type (Fig. 3).

The disappearance of flatness when the feet are relieved of weight, and its reappearance when weight-bearing is resumed, constitute evidence of the mobility of the feet and of the action of the short tendo achillis.

The patient usually can correct the deformity by voluntary muscular effort. He does so best if he stands on tiptoe (Fig. 4), since this eliminates the effect of the short tendo achillis. If the heels are on the ground, he can still correct the deformity by muscular effort, although with difficulty and only with the assistance of accessory muscles (Fig. 5). The statement frequently is made that flat feet which are capable of correction by muscular effort cause little functional incapacity. Such is not the case with hypermobile flat-foot with short tendo achillis which, in spite of its mobility and capability of correction by muscular effort, is the source of great disablement.

Shortness of Tendo Achillis and Limitation of Dorsiflexion at Ankle Joint

If movement at the ankle joint is examined carefully, it can be demonstrated that its range in dorsiflexion is greatly limited. To obtain comparable results with this test, it is necessary that the knee be fully extended while movements of the ankle joint are tested; otherwise variations in the tension of the gastrocnemius will modify the range of dorsiflexion at the ankle. It is equally important to ensure that only movement at the ankle joint is permitted. For this purpose, movement at the subtalar and mid-tarsal joints must be eliminated by the manner in which the foot is held (Fig. 6). When examined with

careful observance of these details, the hypermobile flat foot with short tendo achillis displays a remarkable limitation in the range of dorsiflexion at the ankle (Fig. 7). This never reaches a right angle and frequently falls short of it by as much as 25 degrees (that is, the angle of greatest dorsiflexion is 115 degrees). In normal feet, the angle of greatest dorsiflexion may reach 20 degrees beyond the right angle (that is, the angle of greatest dorsiflexion is 70 degrees).

This limitation of dorsiflexion at the ankle joint is due to shortness of the triceps surae

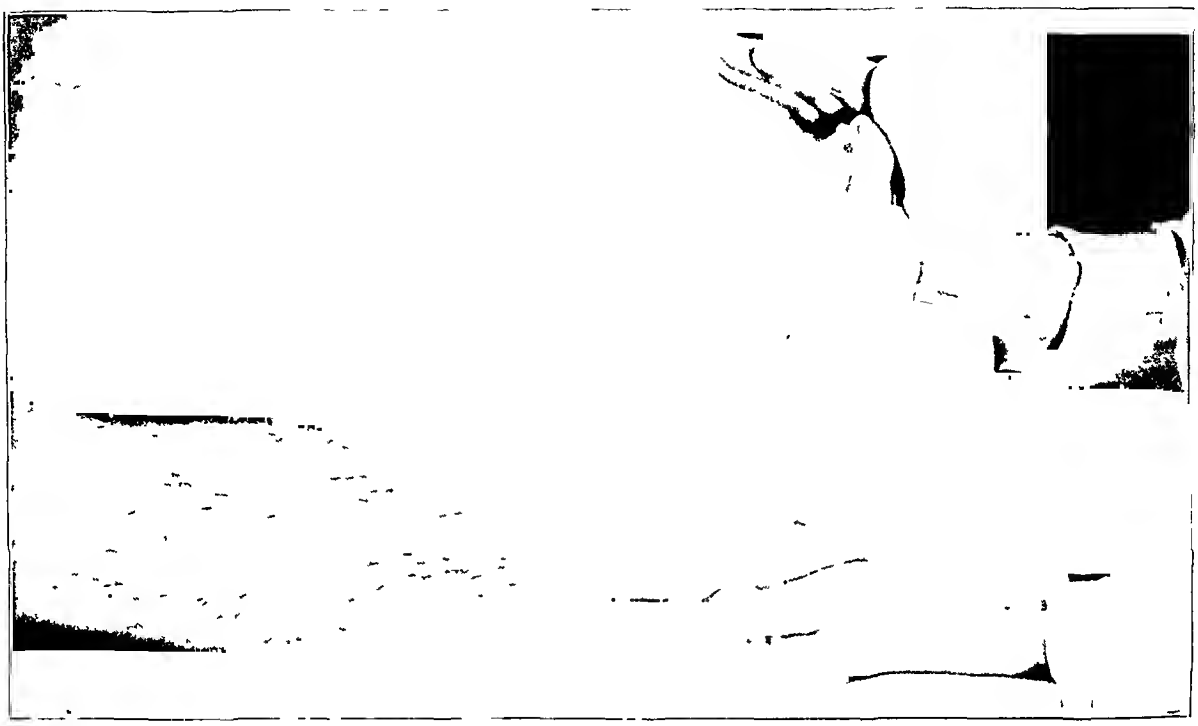

Fig. 6

Manner of examining the foot to determine the limit of dorsiflexion at the ankle joint. The knee is fully extended; the foot is held in such a manner as to eliminate movement of the subtalar and mid-tarsal joints; only ankle-joint movement is permitted. It can then be demonstrated that the foot fails to reach a right angle because of the shortness of the tendo achillis. (Same case as illustrated in Fig. 2.)

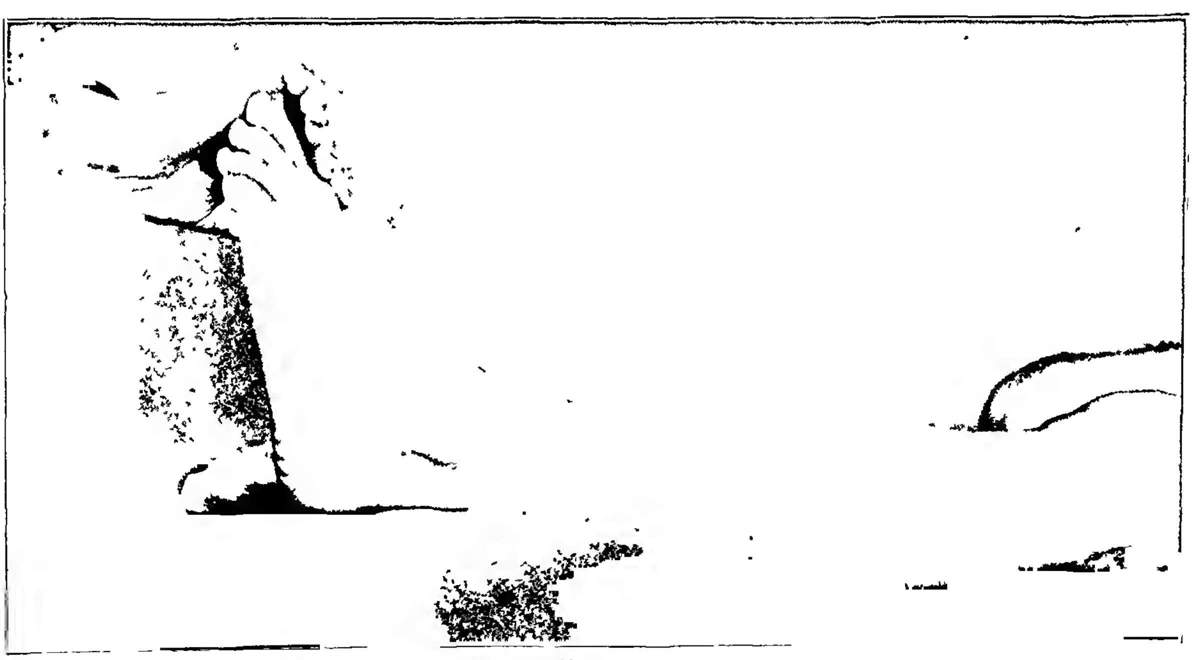

Fig. 7

Shortness of the tendo achillis in hypermobile flat-foot. In this case, the foot fails by 30 degrees to reach a right angle.

Fig. 8-A

Fig. 8-B

Fig. 9

Hypermobile flat-foot with short tendo achillis of moderate severity (same case as illustrated in Fig. 2). Illustrating the various elements in dorsiflexion of the fore part of the foot.

Fig. 8-A: Up to the point shown, the movement takes place at the ankle joint, and the foot remains normal in shape.

Fig. 8-B: Further dorsiflexion of the fore part of the foot is accomplished by upward and outward swing of the fore part of the foot, which occurs at the mid-tarsal and subtalar joints and is associated with the development of the deformity of flat-foot.

Fig. 9: Double-exposure photograph, to illustrate the features described in Figs. 8-A and 8-B.

gastrocnemius and soleus, plus the tendo achillis). It should be noted that the phrase "with short tendo achillis" is used to indicate shortness of the whole plantar-flexing mechanism of the foot. Furthermore, the term does not imply that the short triceps surae is the *cause* of this type of flat-foot, but merely that it is a characteristic part of the clinical picture. The basic cause lies in the structure of the talus and calcaneus, and possibly also in the hypermobility of the tarsal joints. The shortness of the tendo achillis probably develops because the structure of the foot and the laxity of the tarsal joints deprive it of tension stresses, which normally in youth would facilitate its elongation.

Hypermobility of Subtalar and Mid-Tarsal Joints

The limitation of dorsiflexion at the ankle joint is concealed, and on casual observation may be overlooked, because of another and equally characteristic feature of hypermobile flat-foot with short tendo achillis,—namely, an undue laxity and an abnormally increased range of mobility at the subtalar and mid-tarsal joints (talocalcaneal, talocalcaneonavicular, and calcaneocuboid joints). Normal movement in these related tarsal joints is complex, but the separate elements combine to permit inversion and eversion of the foot. All elements of this complex movement are greatly increased in range in the type of flat-foot under discussion, particularly abduction of the fore part of the foot and dorsiflexion at the mid-tarsal joint. Because of this greatly increased range of movement at the subtalar and mid-tarsal joints, the fore part of the foot can swing upward and outward to an unusual degree (Figs. 8-A and 8-B), but it accomplishes this by an associated valgus of the heel, bulging of the inner margin of the foot, and relative depression of the head of the talus. The increase in the sweep of the foot upward and outward is sufficient to permit the heel to come down on the ground in spite of the short tendo achillis. Upward movement (dorsiflexion) of the fore part of the foot, therefore, consists first of dorsiflexion at the ankle joint, to which is added an upward and outward swing which takes place at the mid-tarsal and subtalar joints, accompanied by valgus of the heel and bulging and depression of the medial margin of the foot. Up to the limit of dorsiflexion at the ankle joint, the foot can

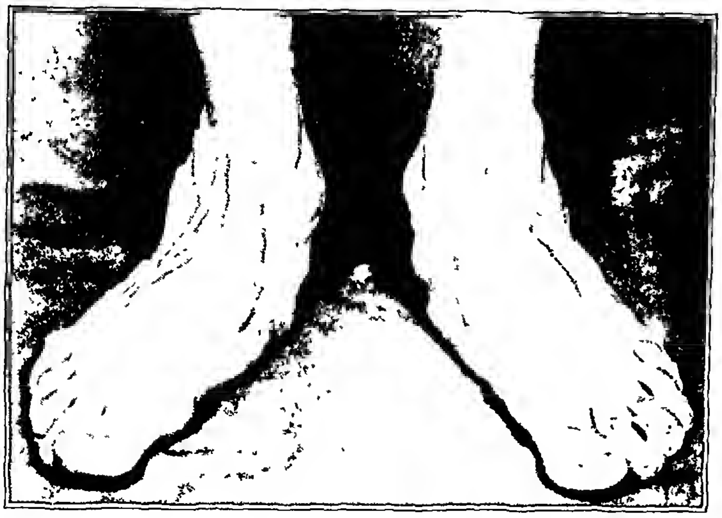

FIG. 10

FIG. 11

Fig. 10: Shows the characteristic deformity of severe hypermobile flat-foot with short tendo achillis.
Fig. 11: Severe hypermobile flat-foot with short tendo achillis (same case as Fig. 10). The head of the talus projects prominently on the medial margin of the foot, and is depressed to such a degree that it reaches the floor.

remain normal in shape; but as soon as this limit has been reached, further dorsiflexion of the fore part of the foot, necessary to permit the heel to reach the ground, can only be accomplished by a movement which at the same time breaks the foot medially at the mid-tarsal joint and produces flat-foot.

Instability of the Subtalar and Mid-Tarsal Joints

A further clinical characteristic of hypermobile flat-foot with short tendo achillis is the instability of the subtalar and mid-tarsal joints. Upon examination of the range of dorsiflexion at the ankle joint, it is not easy to eliminate movement at the subtalar and mid-tarsal joints because, with every attempt to dorsiflex the foot at the ankle, the fore part of the foot tends to "flip out" into valgus. There is only one narrow segment in its arc of lateral movement in which pressure against the ball of the foot produces only movement at the ankle joint. So precise is the position in which the foot must be maintained to limit movement to the ankle joint, that the slightest shift to one side or the other permits the fore part of the foot to slip off its point of balance, either medially or laterally (usually the latter). It feels as though it were balanced on a point centered on the head of the talus. If it is maintained in exactly the correct position, considerable force can be applied to the ball of the foot. When the point of balance is lost, the fore part of the foot suddenly slips out and up through its whole range of movement, without any resistance until the limit of valgus has been reached (Fig. 9).

Characteristics of the Deformity

The flat-foot deformity is severe and of a distinctive type (Figs. 10 and 11). Although familiar to everyone who deals with foot problems, it is worth recording here in detail. The fore part of the foot is swung out in relation to the hind part so that their long axes meet at an obtuse angle, the apex of which is medial. The general position of the foot is one of external rotation in relation to the leg. Since the feet most often are placed so as to point forward, this relationship is manifested by internal rotation of the leg in relation to the foot. The head of the talus is thrust downward and inward, producing the bulge which is the apex of the angle between the fore part of the foot and the hind part. Sometimes it is depressed so far that it actually reaches the ground. The calcaneus is tilted into valgus. The lateral malleolus is buried in the laterally displaced foot; the medial malleolus projects prominently, together with the head of the talus. The whole of the sole of the foot is in contact with the ground and, if foot imprints are made which record the distribution of

weight, it can be demonstrated that weight is distributed nearly uniformly throughout the whole area in contact with the ground (Fig. 12).

Variation in the Degree of Deformity

As might be expected from its origin in a congenital anomaly of structure, this type of flat-foot varies in degree of severity. Every gradation of the deformity can be found in a series, from the mildest case, which might not easily be recognized except by one familiar with the lesion, to the most extreme deformity, such as that shown in Figures 10 and 11. This tremendous variation in the degree of deformity is one of the striking features of the syndrome, and one which makes the problem complex: First, it makes the diagnosis of the mild cases difficult; the severe degrees are easy to recognize, but at the other end of the scale, the lesion shades off by imperceptible gradations into the manifestations of a normal foot. Second, it makes assessment of function difficult. To recognize that hypermobile flat-foot with short tendo achillis exists, does not automatically permit an assessment of function. That depends upon the degree of deformity. Third, it renders treatment complex, since the severe degrees require treatment radically different from that needed for the mild cases

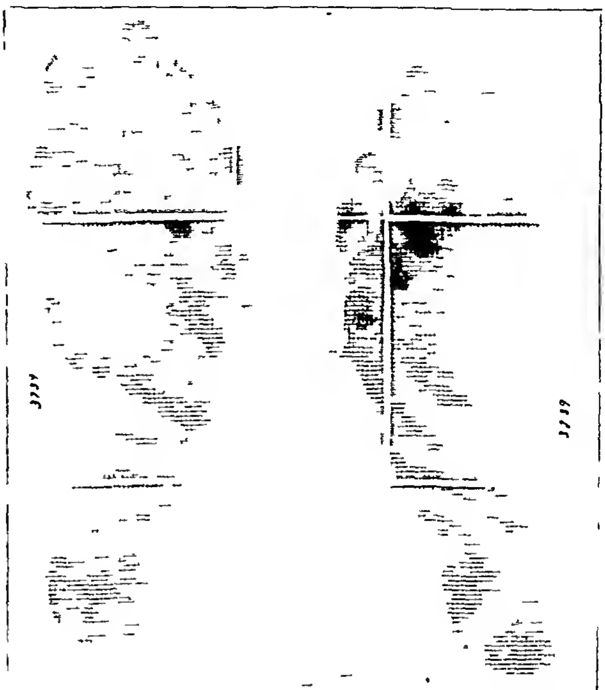

FIG 12

Footprints of hypermobile flat-foot with short tendo achillis of moderately severe degree (same case as illustrated in Fig 2)

Recognition of the existence of this condition marks merely the beginning of a complex problem in management, which is modified profoundly by the degree of deformity which is present.

The natural tendency of the deformity to become more severe and certainly more incapacitating with increasing age should also be noted. In childhood, disability is slight. It may not manifest itself until adolescence. In young adult life, with the burden of increasing weight and strenuous activities, it becomes more troublesome, and by middle life it may have reached severe proportions.

Incidence

The incidence of severe hypermobile flat-foot with short tendo achillis is not very high,—about one case in every 145 men examined The mild form of this condition is nearly eight times more frequent The incidence of the various types of flat-foot among 3,619 Canadian soldiers was as follows:

Severe hypermobile flat-foot with short tendo achillis	25
Mild hypermobile flat-foot with short tendo achillis	192
Peroneal spastic flat-foot	74
All other cases of low arch .	524

ANATOMICAL FEATURES

The peculiar clinical features of this type of flat-foot suggest that its cause may lie in

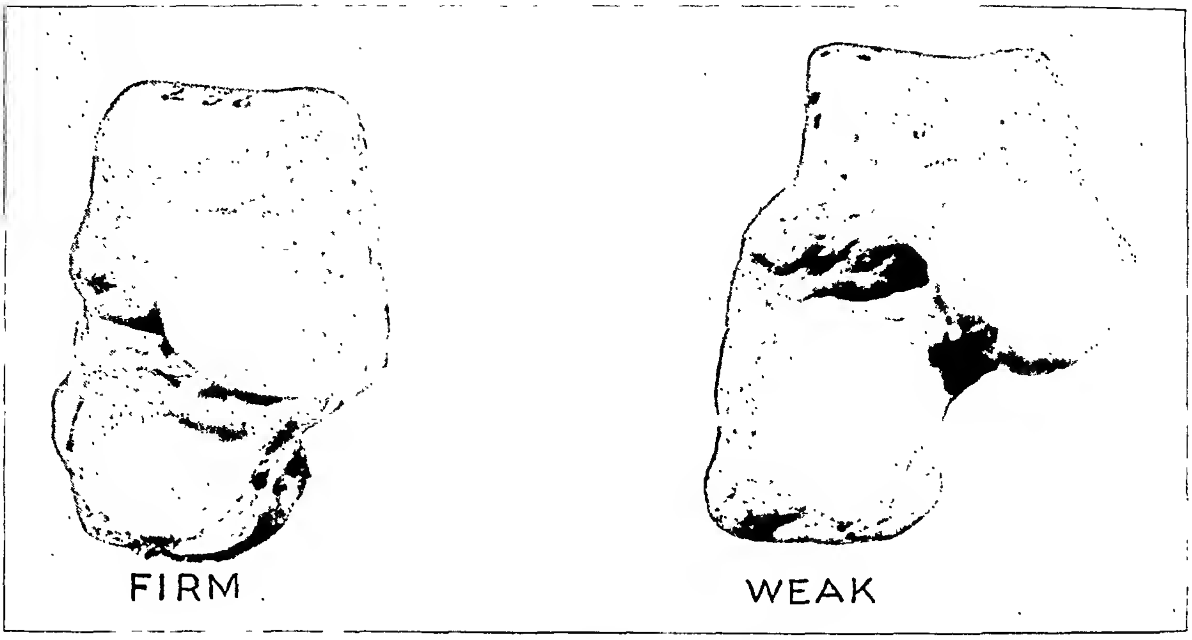

Fig. 13

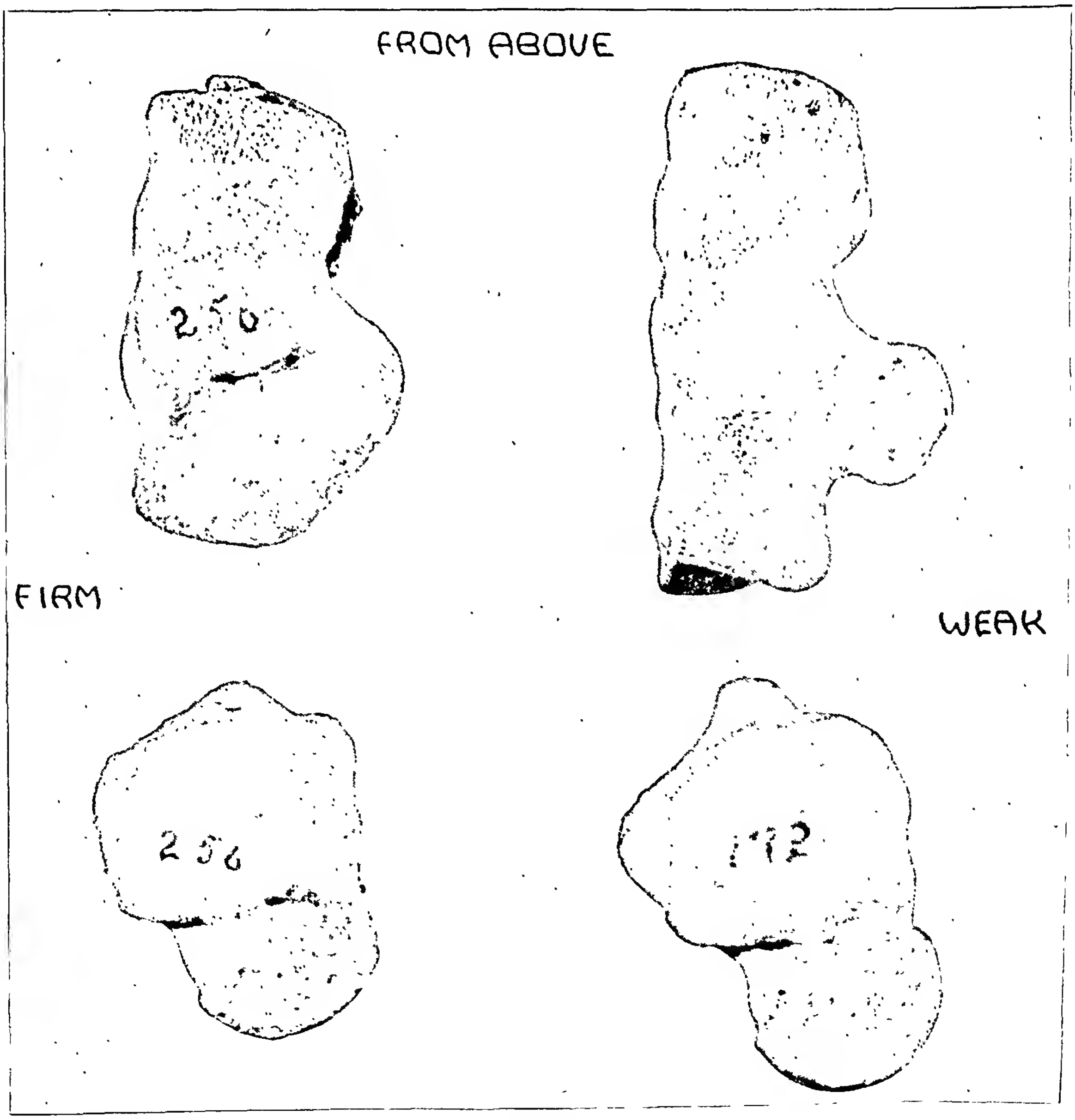

Fig. 14-A

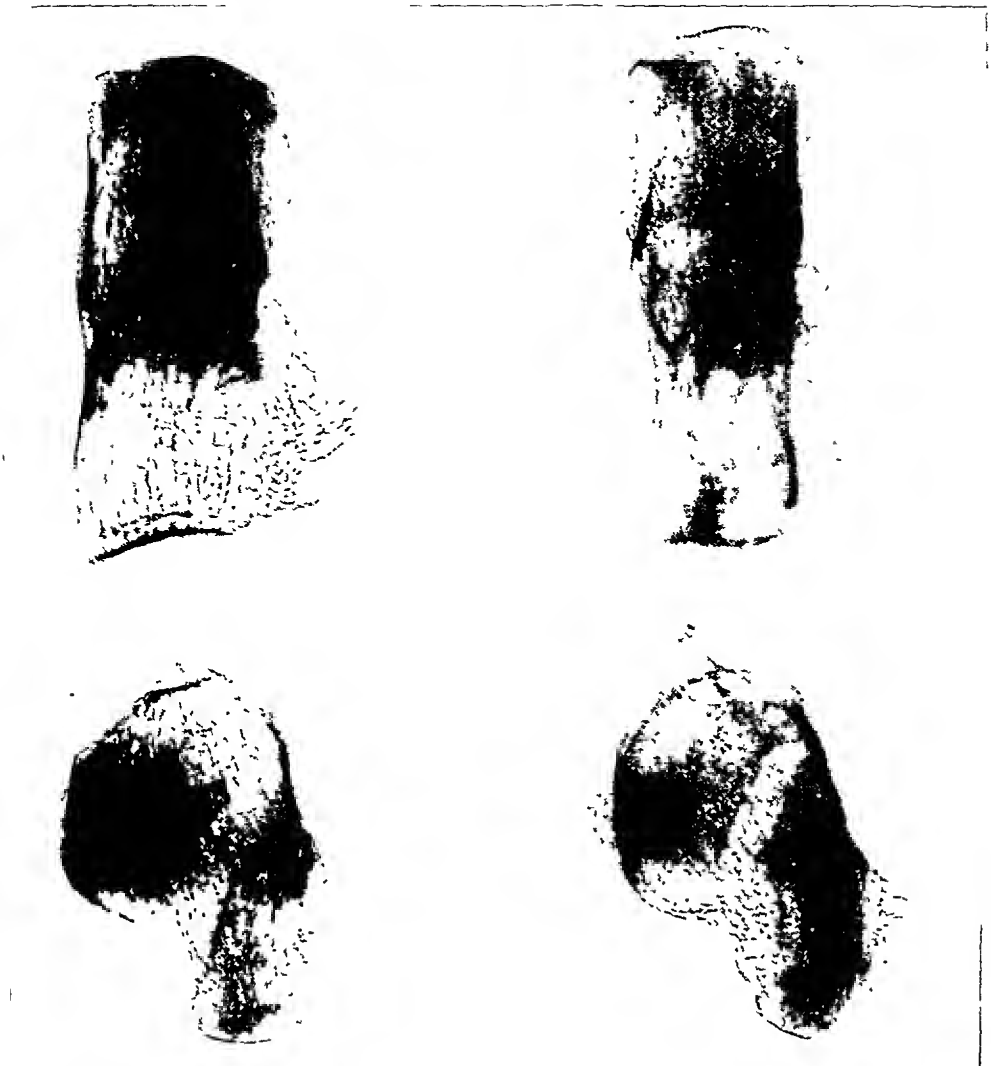

FIG. 14-B

Fig. 13: Anterior view of anatomical specimens which illustrate the extremes of firm and of weak support of the head of the talus by the anterior end of the calcaneus, observed in the examination of the feet of 200 cadavera.

With *firm* support, the center of the head of the talus lies nearly over the center of the anterior end of the calcaneus and nearly flush with it

With *weak* support, the center of the head of the talus lies far medial to the center of the anterior end of the calcaneus. The head of the talus projects forward from the anterior end of the calcaneus. There is no contact between them, no articulation, and no support.

Figs. 14-A and 14-B: Photograph (Fig. 14-A) and roentgenogram (Fig. 14-B) of the anatomical specimens illustrated in Fig. 13, now disarticulated and viewed from above.

With *firm* support of the head of the talus, the sustentaculum tali is broad, rounded, and runs forward to the anterior margin of the calcaneus. The articular facet on the anterior margin of the calcaneus is continuous with the sustentaculum tali.

With *weak* support of the head of the talus, the sustentaculum tali is a narrow tongue-like process, springing from the medial side of the calcaneus far back, and from a narrow base. No facet is present at the anterior end of the calcaneus for the head of the talus.

some abnormal relationship of the talus to the calcaneus. It is difficult, otherwise, to visualize a mechanism which will permit such a great upward and outward swing of the fore part of the foot. Through the courtesy of Professor J. C. B. Grant and the interest of Professor H. A. Cates of the Department of Anatomy of the University of Toronto, studies of the tarsal bones were undertaken by Professor Cates. The studies revealed wide

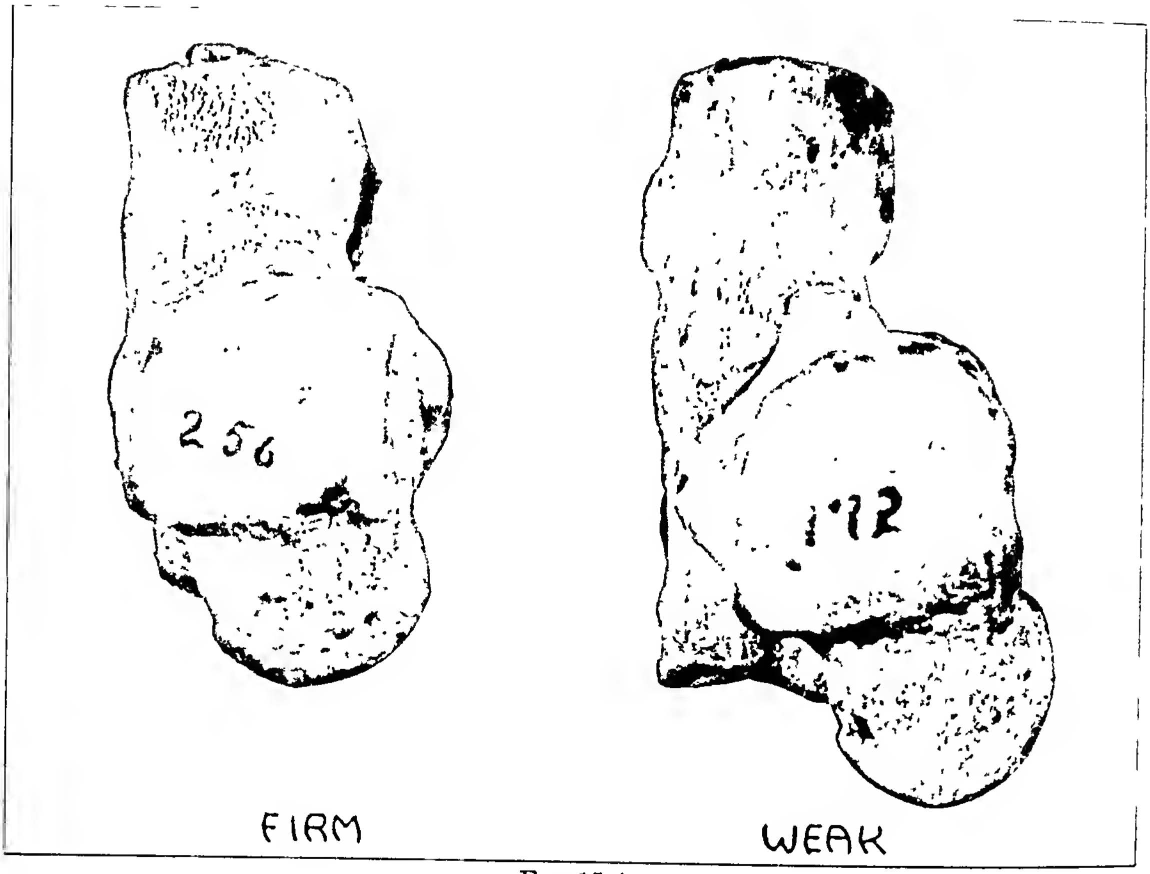

FIG. 15-A

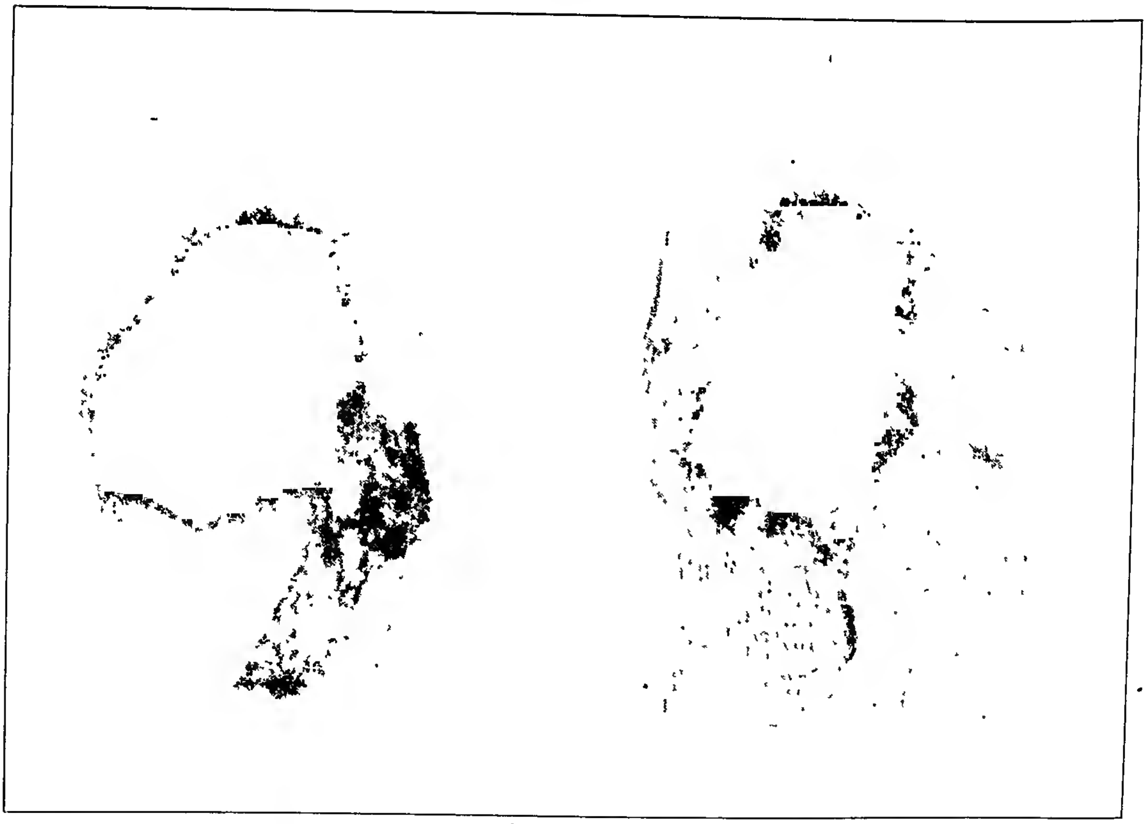

FIG. 15-B

Photograph (Fig. 15-A) and roentgenogram (Fig. 15-B) of the anatomical specimens illustrated in Fig. 13, now articulated and viewed from above.

Firm Support of Head of Talus: The head and neck of the talus are short and thick. The head of the talus is superimposed upon the anterior end of the calcaneus. The calcaneus tends to be short and thick.

Weak Support of Head of Talus: The head and neck of the talus are elongated and project forward beyond the anterior end of the calcaneus. The head of the talus lies anterior and medial to the anterior end of the calcaneus, and is not superimposed upon it.

variations in the relationship of the talus to the calcaneus, especially with reference to the manner in which the head of the talus is supported by the anterior end of the calcaneus. Since the weight of the body is transmitted in considerable part through the head of the talus, the manner of its support will greatly influence its range of movement and its position under stress, and the manner in which it is interlocked in the tarsus will influence the range of movement of the more distal tarsal bones.

Figures 13 to 16-B illustrate four different views of two sets of tali and calcanei. These were selected from the foot bones of 200 cadavera in the Department of Anatomy, University of Toronto, to illustrate the extremes, within this group, of good support and of poor support of the head of the talus by the anterior end of the calcaneus. From the photographs and the roentgenograms of these specimens, certain features can be observed which

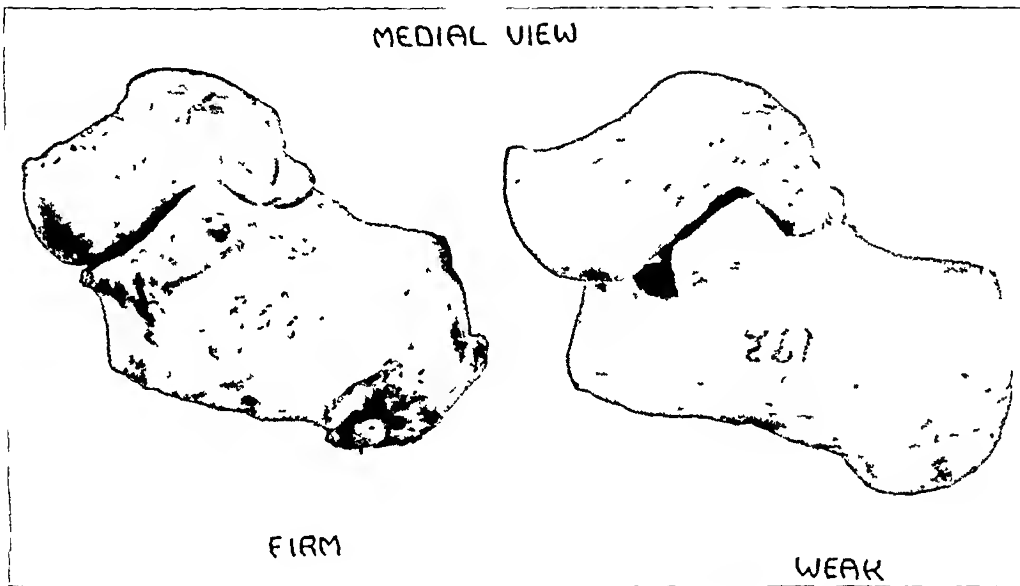

FIG. 16-A

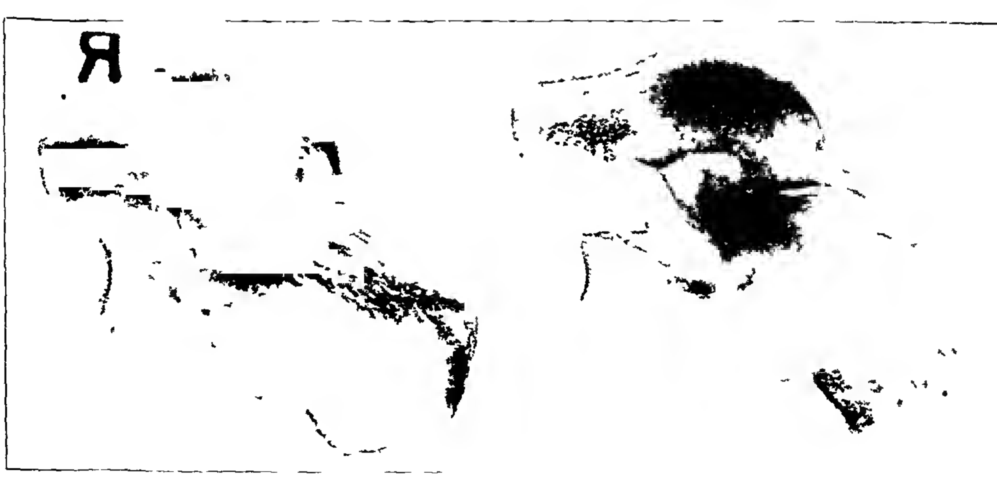

FIG. 16-B

Photograph (Fig. 16-A) and roentgenogram (Fig. 16-B) of the medial view of anatomical specimens illustrated in Fig. 13.

Firm Support of Head of Talus. The head of the talus is supported by an articular surface, which is continuous from the sustentaculum to the anterior margin of the calcaneus.

Weak Support of Head of Talus. There is no facet in this specimen between the anterior end of the calcaneus and the head of the talus. The sustentaculum is narrow and supports the neck only, far back

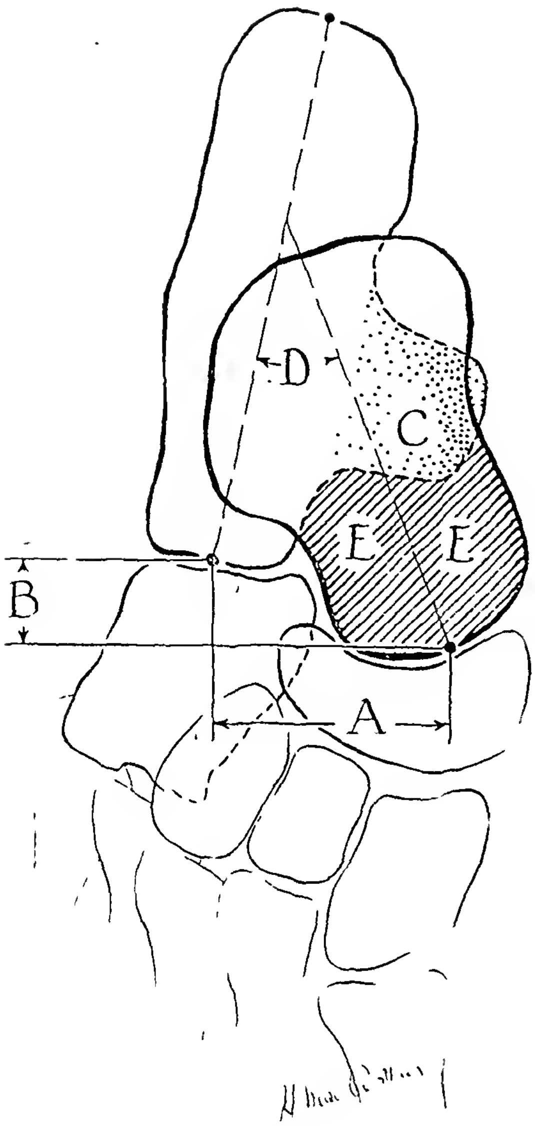

FIG. 17

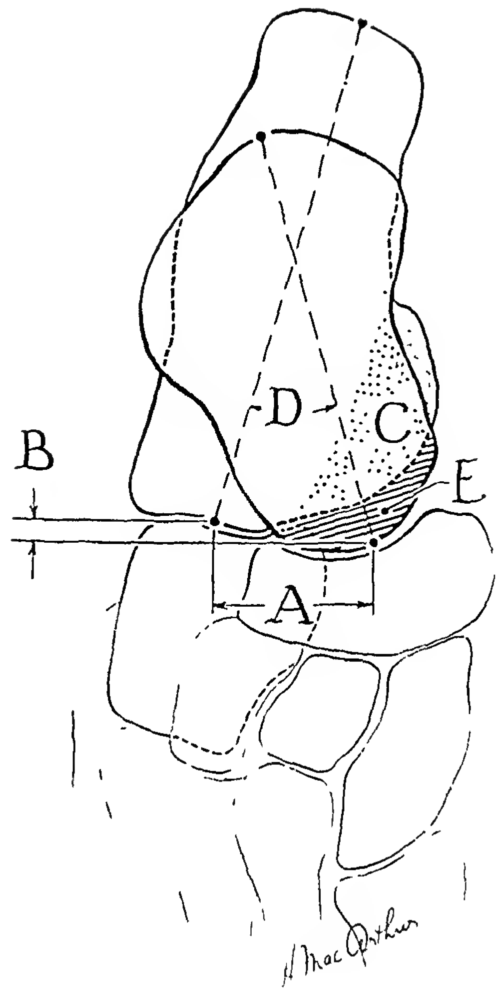

FIG. 18

Fig. 17: Tracing from a standardized roentgenogram, to indicate the various measurements which yield information regarding inadequate support of the head of the talus by the anterior end of the calcaneus.

A: Medial displacement of the head of the talus,—the amount of which is a rough measure of the severity of the clinical picture.

B: Anterior projection of the head of the talus, which brings it farther forward than the anterior end of the calcaneus.

C: Position and shape of sustentaculum. It springs from the medial side of the calcaneus, some distance back from the anterior end and from a narrow base. Its shape is tongue-like. There is an abrupt angle where it joins the calcaneus. The anterior margin of the sustentaculum does not run forward to support the head of the talus. It provides support only to the neck of the talus.

D: Divergence of the long axis of the talus from that of the calcaneus. This is greater than in a normal foot.

E: Extent of the shadow of the head and neck of the talus, which is not imposed upon the shadow of the underlying calcaneus. Several of the preceding factors (medial displacement of the head of the talus, anterior projection of the head of the talus, and shape of the sustentaculum) result in a greater-than-normal area of the head of the talus lying free of underlying calcaneus. The roentgenogram projects this as a shadow of the head of the talus, not imposed upon the shadow of the calcaneus. The extent of this free shadow of the head of the talus becomes a useful index of the degree of inadequate support of the head of the talus.

Fig. 18: Tracing from a standardized roentgenogram of a foot, showing good support of the head of the talus by the calcaneus. (For contrast with Fig. 17.)

are described in the legends accompanying the illustrations. Those features shown in the example of weak support of the head of the talus are important, since it has been possible to reveal, by means of roentgenograms, similar structural relationships in the authors' cases of hypermobile flat-foot with short tendo achillis with such constancy that we believe them to be the basic cause of this type of flat-foot.

The differences demonstrable in the anatomical specimens indicate that wide varia-

FIG. 19

Features of weak support of head of talus by anterior end of calcaneus, as illustrated by the standardized roentgenogram of the case illustrated in Fig. 2. Note that the head of the talus is displaced medially and is far forward. The sustentaculum springs from the body of the calcaneus, far back and at an abrupt angle. There is a large area of the head of the talus which is unsupported by the calcaneus. Compare with Figs. 17 and 18. The footprint of this patient is shown in Fig. 12.

tions exist in the support which is given to the head of the talus by the anterior end of the calcaneus. The head of the talus may be placed solidly upon the calcaneus and everywhere in contact with it, and so firmly supported that superimposed weight will not shift its position. This is illustrated by the example of firm support. On the other hand, the head of the talus may lack completely any contact with the anterior end of the calcaneus and, in addition, it may be displaced so far medially that, under load, there must be an inevitable tendency for it to be thrust downward and for the calcaneus to be tilted into valgus. In the example of weak support of the talus, the absence of any anterior facet leaves the talus supported only by the sustentaculum, and this is so far back as to provide only the most precarious support.

Examination of the specimens cannot but suggest that weak support of the head of the talus is the cause of hypermobile flat-foot with short tendo achillis. The medially displaced head of the talus, without underlying bony support, can be maintained in position only by muscular and ligamentous support. It is incomparably less stable than a talus which is based firmly upon the underlying calcaneus. It is easy to believe that weight-bearing from childhood would cause such a talus to be pushed downward and inward, while the fore part of the foot twists upward and outward.

ROENTGENOGRAPHIC STUDIES

In order to explore the possible relationship between weak support of the head of the talus and hypermobile flat-foot with short tendo achillis, roentgenographic technique was evolved by means of which uniform, standard supero-inferior, lateral, and oblique projections were obtained, of such a quality as to produce an equally good image of all of the bones of the foot [8]. The feet of 3,619 young Canadian soldiers were x-rayed by this

technique, and the standardized films so obtained were studied and correlated with clinical findings and with functional capacity, as judged by performance under the stress of military training. With the extensive experience gained in the Canadian Army Foot Survey, we can state that such roentgenograms are a valuable means of studying the structure of the foot and of correlating it with deformity and with function.

In general, the findings of this study demonstrate that there is a close parallelism between weak support of the head of the talus (as demonstrated by the standard roentgenograms) and the presence of hypermobile flat-foot with short tendo achillis. The roentgenographic evidence of weak support of the head of the talus is nearly always present in this condition, and its degree corresponds closely to the severity of the clinical picture. *The authors believe that inadequate support of the head of the talus is the important basic cause of hypermobile flat-foot with short tendo achillis.*

Roentgenographic Evidence of Weak Support of the Head of the Talus

The standardized roentgenograms were closely comparable to the roentgenograms of the anatomical specimens, so that the structure of the foot could be interpreted from study of the anatomical specimens. The important points indicating weak support of the head of the talus, which can be determined from the supero-inferior roentgenograms, are illustrated diagrammatically in Figure 17.

Figures 19, 20, and 23 show the roentgenographic appearance, in the supero-inferior projection, of feet displaying weak support, average support, and firm support of the head of the talus.

Roentgenograms can never replace clinical examination in the diagnosis of hypermobile flat-foot with short tendo achillis. The value of roentgenographic studies lies in the

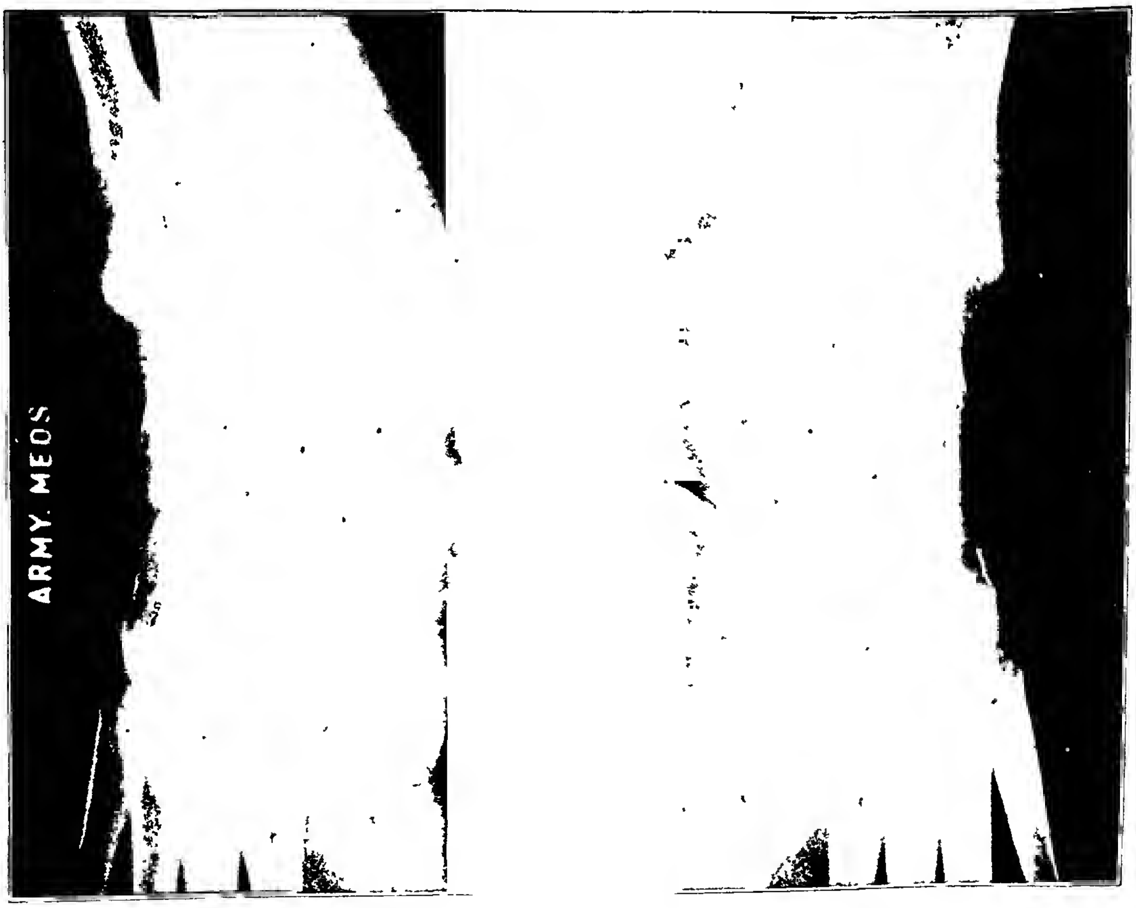

Fig. 20

Features of average support of head of talus, as seen in the standardized roentgenogram. Compare with Figs. 17, 18, and 19.

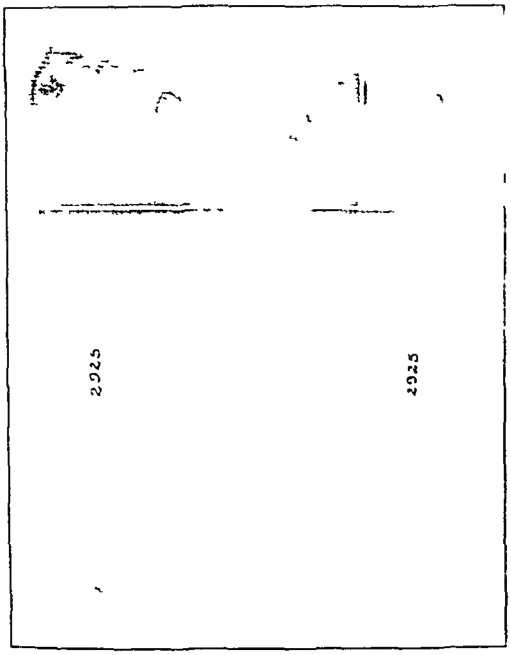

Fig 21

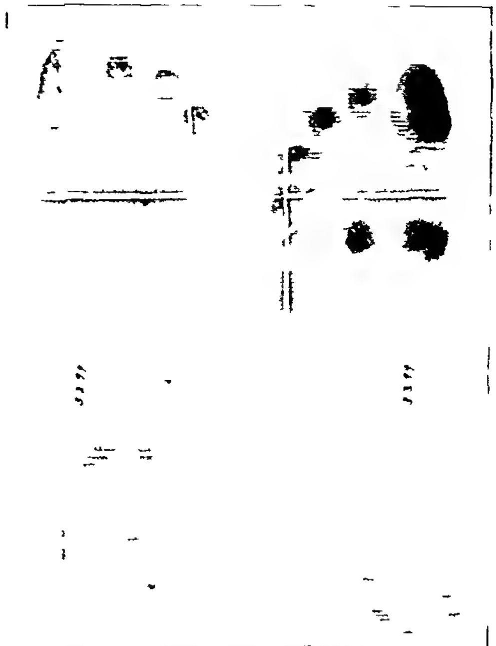

Fig 22

Fig 21 Imprint of the feet illustrated in Fig 20 There is average support of the head of the talus, and no depression of the arch

Fig 22 Imprint of the feet illustrated in Fig 23 Mild claw-foot is manifested by the high arch and localized pressure under the heads of the metatarsals

Fig 23

Features of firm support of the head of the talus, as seen in the standardized roentgenogram This was a case of mild claw-foot

light they throw upon the relationship of bony structure to deformity and function. It is a technique of research, by means of which we may secure otherwise unobtainable information regarding the skeletal structure of feet, the appearance and function of which can be assessed by clinical examination. In the problem of diagnosis, roentgenograms supplement, but do not replace, clinical examination. Hypermobile flat-foot with short tendo achillis can be recognized best by its distinctive clinical features,—short tendo achillis, hypermobility and instability of tarsal joints, and deformity which is present only when weight is borne upon the foot.

SUPPORT OF THE FOOT

Passive Support by Bones and Ligaments versus Active Support by Muscle Power

In this paper the conception is advanced that the function of the foot and its shape under the stress of weight-bearing depend chiefly upon the design of the tarsal bones and their position in relation to each other. Deficiencies in structure of the talus and calcaneus result in a weak, flat foot; conversely, the foot will be strong and well shaped if the tarsal bones are so shaped and so fitted into each other that they cannot shift when weight is imposed upon them. Since this conception is contrary to the widely accepted view that muscle power is the important factor in maintaining the shape and strength of the foot, some discussion of these opposing views is necessary.

Lack of accurate knowledge of the physiology of the foot, and particularly of the relationship of its structure to its function, makes it difficult to assess the relative importance of the passive factors (bones and ligaments) as compared with the active factors (muscles) which provide support to the foot. In most discussions on foot function, it is implied that the body structure of the foot follows a fixed pattern. In consequence, it is assumed that the support which is provided to the foot by its bony framework is the same in every foot, and that variations in the strength of the foot are dependent to a great degree upon the power of muscles.

The information derived from the Canadian Army Foot Survey and from previous studies leads us to the conclusion that, in the foot more than in any other part of the body, variations in the shape of the skeletal units and in their relationship to one another profoundly modify the stability, the shape, and the function of the foot. Such variations are common and occur through a wide range. It is incorrect to assume that there is uniformity of bony structure in all feet, or that the support provided by the architecture of the foot is virtually the same in every case. The tarsal bones, especially the talus and calcaneus, vary in their shape, in their position relative to one another, and in the manner in which they articulate with one another. These variations occur through such a wide range that it is impossible to define precisely what is normal. It is clear, however, that at one extreme of the range of variation the relationship of the tarsal bones to one another is unstable. Even with the aid of support from ligaments and muscles, they are ill-adapted to weight-bearing and can readily be distorted by superimposed stress. At the other extreme, the shape of the tarsal bones and their relationship to one another is such that they virtually interlock; and the more weight they bear, the more firmly they settle down into one another (Figs. 13 to 16-B).

One might compare the leg and foot to an obelisk (the tibia), based on a plinth consisting of two superimposed foundation stones (the talus and calcaneus). If the foundation stones are smoothly cut with all surfaces at right angles to each other, if they fit accurately and are precisely superimposed upon one another, and if they rest upon a level foundation, the weight of the shaft is carried without danger of collapse. Should the foundation stones be imperfect in their outline, tilted, or not accurately superimposed on one another, the weight of the column is off center and the structure is unstable (Fig. 24).

It is impossible, therefore, to discuss the problem of weak feet without taking into

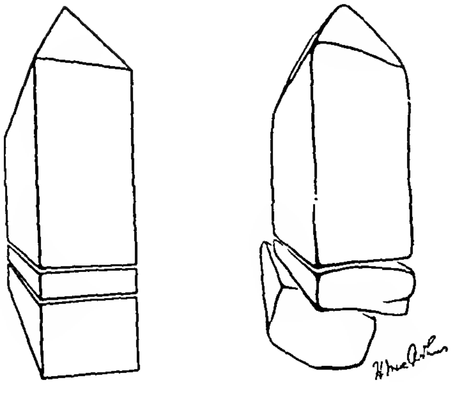

FIG. 24

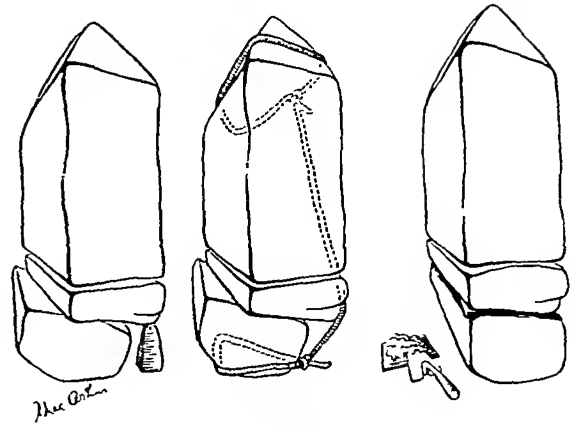

FIG. 25

Fig. 24: Sketch to illustrate structures analogous to strong and weak feet. An obelisk of well-cut and well-fitted stones is stable and supports weight without difficulty. If the stones are irregular in shape, poorly fitted, and badly placed, or if they have slipped, the structure is unstable and shifts when weight is imposed upon it.

Fig. 25: Diagram illustrating the various principles of treatment for hypermobile flat-foot with short tendo achillis. (a) The weak skeleton may be supported by an external prop,—for example, a Whitman plate. (b) The muscles and their tendons may be utilized as slings to support the unstable skeleton. Increased muscle power by exercise increases the efficiency of this mechanism. (c) The unstable skeleton may be made stable by fusion, as are the stones by cementing them together.

consideration their bony framework. Moreover, it is useless to discuss structure in general terms; it must be related specifically to each particular flat foot. Feet are as individualized in their structure as are other parts of the body; but, while variations in structure make no difference in the function of noses, ears, or even hands, they are important with feet. Efficiency in weight-bearing and propulsion is profoundly influenced by their skeletal structure.

While the stability of the foot and the maintenance of its normal shape depend to a great extent upon its bony structure, this does not exclude contributions to its support from ligaments and muscles.

It is not easy to determine exactly the part which ligaments play in providing support to the foot, since direct study of their function is difficult. It seems reasonably certain, however, that some ligaments provide direct support to superimposed structures (such as the spring ligament supporting the head of the talus); while others, by limiting movement at the tarsal joints, prevent displacement into positions of instability (perhaps the interosseous talocalcaneal ligament).

The contribution of the muscles to the support of the foot is more easily ascertained, even though the mechanism of their functioning is complex to the point of confusion. It is possible for muscles to maintain the normal shape of the feet and to support the load imposed upon them, provided the feet are not rigid. The effort involved in doing this will vary with the adequacy of the support provided by the skeletal framework. This is well exemplified by the type of flat foot under discussion. Its deformity can be corrected by muscle power, although this involves an unusually great effort and calls into play muscles not commonly used. This muscle mechanism is only for occasional use, however. It involves too much effort to be long maintained. In few cases of hypermobile flat-foot with short tendo achillis is the deformity eliminated by the use of the muscles, even though they can be used for this purpose on occasion.

The support and stability which are provided the foot by its bony structure vary from foot to foot within wide limits. The task in load and balance which remains for the muscles varies inversely with that assumed by the bony framework. The strongest, most stable foot is that in which the tarsal bones interlock with one another in such a manner as to transmit the body weight directly to the ground. Such a foot requires its muscles only for fine

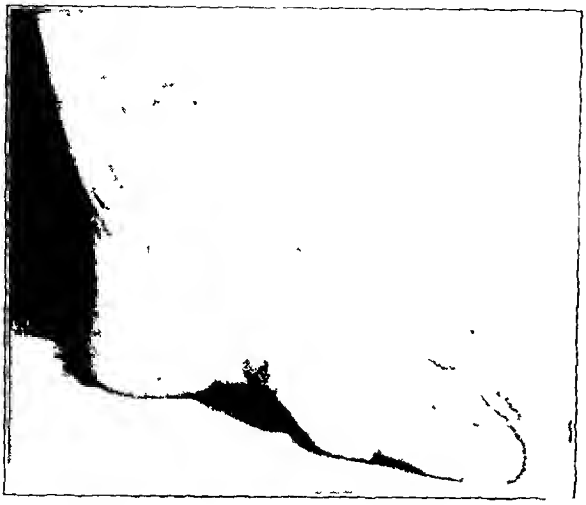

FIG. 26

A foot completely paralyzed from poliomyelitis for thirty-five years. It is not flat, even when weight is imposed upon it. Its arch is maintained by a stable tarsus.

adjustments of balance, and for accommodation to irregularities in the ground. The less stable the bony framework, the greater is the load thrown upon the muscles. The severe cases of hypermobile flat-foot with short tendo achillis represent the extreme of skeletal instability and the maximum of muscular effort.

That bony structure is of greater importance than muscle power in providing support to the foot is illustrated by the well-known observation that feet, completely paralyzed by poliomyelitis, often have little deformity. Even in the complete absence of any muscle power to control the position of the foot, flat-foot usually does not occur. In such cases, the maintenance of a normal contour of the foot and the freedom from symptoms of foot strain must necessarily be due solely to a stable relationship of the skeletal units of the tarsus (Fig. 26).

In summary we may state that support is provided to the normal foot both by passive factors (bones and ligaments) and by active factors (muscles), and that these factors are reciprocal. In the average or strong foot, most of the support is provided by the passive factors; little load is thrown upon the muscles. Much greater stability and strength for the foot can be obtained from the passive support derived from a well-designed skeleton than can ever be provided by muscles. The muscles, however, always play some part in maintaining balance and supporting the load. This function is least when the skeletal structure of the foot is such as to support the body weight without shifting. If the tarsal bones are less favorably placed for weight-bearing, in relation to each other, sufficient support may still be provided to the foot by increasing that which comes from muscle contraction. The less the structural support provided by the skeleton, the greater the contribution demanded from the muscles. Within a wide range of what might be called average feet, the complementary contributions from the skeleton and from muscles provide satisfactory stability and support. When the skeletal units are weakly disposed, however, the load thrown upon the muscles is unduly great, and they cannot sustain it continuously. The strongly disposed tarsal skeleton can sustain the whole body weight without difficulty, but the same is not true of muscles. They can function as important complements to skeletal support, but they cannot alone sustain the body weight for more than a brief period of time.

The *strong foot*, therefore, is one in which the tarsal bones are so shaped and so articulated with each other as to bear the weight of the body without appreciable movement between them. Its muscles are used to maintain balance, to adjust the foot to uneven ground, and, of course, to propel the body in walking or running. The *weak foot* is one in which the tarsal bones are so shaped and are so disposed in relation to each other as to be unstable and to shift in position when weight is imposed upon them. Only by increase in the support provided by the muscles can the normal shape of such a foot be maintained and the body weight supported. There is a limit to the contribution of this type which muscles can make to the support of the foot. They cannot function unremittingly, nor can they ever provide such powerful support as can the skeleton.

In hypermobile flat-foot with short tendo achillis, the skeletal support provided to the foot is subnormal, because of a deficiency in the support provided the talus by the calcaneus. In all its varying degrees from mild to severe, it demands greater effort from its muscles than does the more stably constructed foot. In mild or moderate grades of hypermobile flat-foot with short tendo achillis, the contribution of the muscles to the support of

the foot may be adequate for all average needs, but there is always a limit to the load which can be imposed. In severe cases, there is inability to meet even the moderate demands of a life of quiet activity. In less severe cases, a man may meet the demands of average activity, but will break down under the strenuous life of a soldier.

TREATMENT OF HYPERMOBILE FLAT-FOOT WITH SHORT TENDO ACHILLIS

Obviously no single form of treatment is suitable for all cases of hypermobile flat-foot with short tendo achillis. What is necessary to rescue the severe case from lifelong incapacity is needlessly radical for the mild case. The many factors which must be considered in planning treatment arrange themselves into three groups:

First is the great variation in the severity of the lesion. This is dependent upon the degree to which the tarsal skeleton fails to provide adequate support to the foot. There is every gradation from the normal, completely stable foot, capable of bearing unlimited weight without deformity or disability, to the foot so unsound structurally that it presents the extreme picture of severe hypermobile flat-foot with short tendo achillis. Within this range, widely different treatment is necessary. In the severe cases, permanent relief can be obtained only by operation; only the simplest management is needed in the mild cases.

Second, age modifies both the type of treatment and the lesion itself. The degree of disability caused by the hypermobile flat foot with short tendo achillis increases with advancing decades of life. In childhood, even a moderately severe degree of hypermobile flat-foot with short tendo achillis may cause no symptoms. By adolescence, it is certain to be giving trouble. In young adult life, it will be significantly disabling. At the age of forty and over, the disability may be increased by the growing burden of increasing body weight, by diminishing strength of muscles, and by the development of additional foot problems accessory to the main lesion (hallux valgus, osteo-arthritis, or localized points of pressure on the sole of the foot with callus formation). These changes in the degree of disability are not the result of increasing structural weakness, but of additional stresses which come with advancing years, and the diminished efficiency of the compensatory support provided by the muscles.

Independent of any changes in the degree of disability with advancing years is the important fact that what may be sound treatment in adult life may be bad treatment in childhood. This applies particularly to operative treatment, should it be necessary. The severe cases of hypermobile flat-foot with short tendo achillis can be greatly improved by appropriate surgical procedures, but it is unwise to perform these in childhood. These should be postponed until late adolescence or early adult life.

Third, the effort which is demanded of feet influences profoundly the degree of disability. A life of quiet activity with little physical effort, no strenuous sports, and the opportunity to perform the necessary tasks in the time and manner best suited will often reduce disability to the point where it is insignificant. Conversely, strenuous occupations or sports, especially those which demand long standing or much walking, will result in great incapacity. Such occupations as nursing, laboring, and soldiering are impractical or impossible, if the degree of hypermobile flat-foot with short tendo achillis is more than moderate.

The various measures which may be used for the treatment of hypermobile flat-foot with short tendo achillis fall into three groups (Fig. 25).

1. *Measures to Provide Extraneous Support to the Foot:* This group includes the great variety of accessories and procedures which attempt to support the foot from without (such as arch supports, modifications to boots, and special boots). They are of undoubted value. By supporting the foot, they reduce the load which otherwise would have to be carried by the muscles. There are decided limitations to their usefulness. They do not alter the underlying structural fault, and consequently their effect is only palliative. Also, their

efficacy is low. Even so they have a place in the treatment of this ailment. Those of most value are (1) arch supports of the Whitman type, made from plaster models of the feet and (2) boot modifications. Of these, the most important is raising the heel. A thick inside lift from heel to toe is also of some value.

2. *Exercises to Develop Muscle Power:* Properly planned exercises, persistently and conscientiously carried out by the patient, can increase the power of the muscles which motivate the foot. By their use, the support to the foot which can be provided by the muscles is materially increased. Foot exercises, properly used, are important in the management of hypermobile flat-foot with short tendo achillis, but it must be admitted that frequently the result obtained from a program of exercises is imperfect. There is a limit to the improvement which will follow increased muscle power, no matter how great that increase be. Too often, also, the best result is not obtained, because of imperfect planning of the exercises or failure of the patient to perform his part conscientiously and persistently. The muscle training must be directed to specific muscles (invertors and plantar flexors) and must be maintained continuously for a long period of time. It is possible that improvement in the results obtained by muscle exercise will shortly be achieved by the application of new principles of muscle development, particularly the principle of heavy-resistance exercises, advocated by DeLorme.

3. *Operative Measures in the Treatment of Hypermobile Flat-Foot with Short Tendo Achillis:* For the severe cases of hypermobile flat-foot with short tendo achillis, no form of external support and no program of muscle retraining offers more than palliative relief of symptoms, and even this is imperfect. The patients face a life of semi-invalidism, because of the greatly diminished capacity of their feet to bear weight and to propel their bodies in walking. Since the basis of the lesion is inadequate support of the head of the talus by the calcaneus, so that, under stress, the head of the talus slides medially off the calcaneus, improvement can be obtained by fixation of the talus in suitable relationship to the calcaneus.

This can be accomplished by various operative procedures, but only those which fuse the tarsal bones are of real merit. Hoke's subtalar and mid-tarsal fusion,* presented in 1921, is effective. The loss of movement at the subtalar and mid-tarsal joints is more than compensated by the great increase in stability and strength of the foot. This operation, however, is of considerable magnitude and carries with it a risk of avascular necrosis of the body of the talus, as pointed out by Marek and Schein.

Gallie's subtalar fusion through a posterior approach gives satisfactory fusion of the subtalar joint, but leaves the mid-tarsal joint still unstable and hypermobile. This may mar the perfection of the result.

The authors' present procedure has the merit of simplicity. Through a medial approach, the talonavicular joint and the joint between the sustentaculum tali and the neck of the talus are fused by removal of their articular cartilage and the implantation of cancellous bone grafts. To date the results seem satisfactory, but too short a time has elapsed for adequate assessment. This will be reported in a later paper.

Lengthening of the tendo achillis alone has been advocated and practised for the treatment of hypermobile flat-foot with short tendo achillis. It results in considerable improvement in the foot, since the invertors of the foot can act to greater advantage when freed of the stress imposed by the short tendo achillis. It does not modify the essential structural weakness and, since it materially weakens the power of the triceps surae, it is not a satisfactory procedure.

Operative treatment of hypermobile flat-foot with short tendo achillis, which involves tarsal fusion, should not be undertaken in childhood. The plasticity of the bone at that age will invite recurrence of the deformity, if stress is placed upon the foot, even after successful fusion. Late adolescence or early adult life is best for tarsal arthrodesis.

* This is not Hoke's operation for flat-foot, but that for stabilizing paralytic feet.

We estimate that 10 per cent. of the cases of hypermobile flat-foot with short tendo achillis are suitable for treatment by operation.

General Plan of Treatment

With so many variables in the problem, it is well to outline a general plan of treatment of this lesion. It can best be considered in age periods, as summarized below:

Childhood: Support of the Whitman type; modifications to boots, raising of the heel to reduce tension of tendo achillis, inside lift from toe to heel; muscle exercises to develop power of foot invertors. No operation should be performed, even in severe cases.

Adolescence: Continue Whitman supports and lift to heel. Every effort should be made to develop muscle power. In severe cases a regimen of reduced physical activity is needed. In late adolescence, operation may be performed for the worst cases if the symptoms are justifiably severe.

Young Adult Life: Continue Whitman plates if necessary. Continue use of raised heel if necessary. Operate upon patients with the most severe symptoms. Seek employment within capacity.

Maturity: By this time, some degree of stable adjustment has usually been reached. By trial and error, a mode of living has been achieved which demands the minimum of the feet. Whitman plates may be continued to advantage, and are more useful than special boots.

SUMMARY

The clinical features which distinguish hypermobile flat-foot with short tendo achillis are:

1. A prolonged history of some degree of foot disability extending back into childhood, the degree of disability tending to increase. There is often an hereditary tendency.

2. Flat-foot deformity which is mobile. It disappears when the feet are freed of weight-bearing, and appears when the patient stands. It can be corrected by muscular effort.

3. A short tendo achillis, which limits dorsiflexion at the ankle joint.

4. Hypermobility of the mid-tarsal and subtalar joints.

5. A deformity which is often severe and of characteristic appearance.

Evidence from anatomical and roentgenographic studies shows that hypermobile flat-foot with short tendo achillis results from unstable architecture of the tarsal bones, especially their configuration and position in relation to each other. This results in imperfect support of the head of the talus by the calcaneus.

CONCLUSIONS

The common severe flat-foot deformity of childhood and young adult life is due to abnormalities of the tarsal bones, which result in instability of the tarsus, manifested when weight is superimposed upon the foot. The chief lesion is inadequate support of the head of the talus by the calcaneus. To a degree, the diminished stability and support of the tarsus can be compensated for by increased action of muscles. They cannot fully compensate for the more severe grades, so that flat-foot of a severe degree results. The clinical features of the lesion justify the use of the descriptive title "hypermobile flat-foot with short tendo achillis", to distinguish it from other forms of flat-foot and to indicate the chief features of its clinical picture. Treatment is determined by the age of the patient and by the severity of the lesion. Severe cases are benefited by operation, which should be postponed until late adolescence or young adult life. Mild cases and youthful patients are best treated by foot supports and muscle exercises.

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DISCUSSION

Dr. Frank D. Dickson, Kansas City, Missouri: I applaud Colonel Harris and Major Beath bringing before the Association this important subject of hypermobile flat-foot with short tendo achi We of the orthopaedic group have become so preoccupied with the more dramatic aspects of our speci that we are prone to push aside so prosaic a condition as flat-foot. Royal Whitman said many years a "If one has a cut on the finger or a felon, he goes to the hospital and has surgical treatment. If he h painful foot, he is the subject of ridicule and is sent to the shoe salesman for relief."

Symptom-producing flat-foot is an important part of orthopaedic practice, since it is a widespr medical condition; it is, as well, an economic problem of considerable magnitude. It is, therefore, worthy our careful attention, since the main hope for relief rests with the orthopaedic surgeon. Our experience co cides with that recorded in this paper,—namely, that hypermobile flat-foot with short tendo achillis in so degree is the most common single form of foot imbalance, that it is the most likely to produce sympto and that it manifests itself in childhood and young adult life. This latter fact is important and should constantly held in mind in appraising foot posture in children, for it is at this age that corrective measu should be initiated.

It has long been appreciated that a short heel tendon restricts normal dorsal flexion of the ankle joi In consequence, as weight falls upon the foot, in order that the heel may come down to the ground, the c caneus assumes a valgus position, the head of the talus rotates downward and inward, and the fore part the foot swings upward and out. These complex but correlated movements result in a pronated foot, w concentration of weight stresses on the depressed medial border. In the past, it has been taken for grant that such a faulty foot attitude was due to giving way of the whole foot structure, the result of stretching ligaments and muscle relaxation, following continued excessive stress, and that it was concentrated on t medial side of the foot by reason of the short heel cord. The investigations by Dr. Harris and Dr. Beath of very persuasive evidence that anatomical abnormalities in the os calcis, and to some extent in the astragal resulting in structural faults in the subtalar joint, are the etiological factors in the production not only the pronation of the foot, but of the short tendo achillis as well. This is indeed a new point of view, but o which has sound support. In an extensive series of 3,619 cases, 76 per cent. of the more severe cases of hyp mobile flat-foot with short tendo achillis showed weak support for the head of the astragalus, due to str tural abnormalities of the os calcis; while only 9.1 per cent. showed such structural weakness in normal fe It would seem that the anatomical abnormalities in the os calcis and astragalus, which have been so clea demonstrated, are probably throwbacks to the arboreal foot in which the astragalus, os calcis, and the su talar joint have characteristics resembling those described.

It should be recognized, however, that probably not all cases of hypermobile flat-foot with short ten achillis are due to anatomical faults of the os calcis or the astragalus. In some, the short heel tendon alo is the etiological factor, — at least, I have seen a very considerable number of such patients respond simple lengthening of the heel cord.

Dr. Edwin W. Ryerson, Chicago, Illinois: From this very interesting discussion, one somehow ge the picture that a portion of the astragalus swings inward and becomes displaced. That, I think, is a mi conception. The talus is held very well by the notch into which it fits. Its motions are mostly flexion and e tension, and not lateral deviation. My picture of this kind of flat-foot is that all the rest of the foot, including the calcaneus, navicular, cuboid, and the other bones, swings around the head of the talus and that the talus remains pretty well fixed.

I do not like to lengthen the tendo achillis operatively, because it takes some time for it to unite. It displaces the gastrocnemius and soleus up toward the knee, and the result is that the calf is not as beautiful as it should be. One achieves the same result by inverting the foot and fixing it in a plaster cast for three or

four weeks, and perhaps renewing the cast for another three or four weeks to allow the muscle to stretch. The tendo achillis is not short; the muscle bellies are short, but the tendo achillis is long enough.

Dr. John R. Moore, Philadelphia, Pennsylvania: This paper is very interesting because it revives the probable structural causes contributory to hypermobile flat-foot. Personally, I feel that the authors are overstressing the structural defects and minimizing the importance of the muscles and of posture. I do not feel that a short heel cord can be diagnosed on the basis of the test shown in the moving picture. If this test is the basis for the evidence concerning the short heel cord in this particular type of foot, I question the value of the material. The heel cord must be tested with the knee fully extended and also with the foot at a right angle, in order to determine whether the heel cord and its muscle are at fault, or whether it is the capsule of the ankle joint, or some other possible cause. If the knee is hyperextended during the testing, even a normal heel cord may give the impression of being short, due to the fact that the gastrocnemius originates on the femoral condyles.

One of the authors stated that Dr. Hoke made a mistake in his analysis of flat-foot, by ascribing the principal cause of flat-foot to muscle imbalance. Dr. Hoke did not ascribe the weak foot or the hypermobile foot to muscle imbalance alone, but stressed equally the structural defects and muscle imbalance. He recommended lengthening of the heel cord when it is contracted; and he also recommended a scaphocuneiform arthrodesis for two purposes,—first, to re-establish the normal astragaloscaphoid fulcrum, and, second, to re-establish a sound lever arm for those muscles normally employed in maintaining balance of the arch and foot. I feel that the authors have overstressed the structural defects as possible causes of hypermobile flat-foot.

Dr. John L. McDonald, Toronto, Ontario, Canada: I want to compliment Dr. Harris and Major Beath for their presentation, and also to express my appreciation for the way in which they explained the underlying cause of flat feet in children and young adults. Most of us are thoroughly familiar with the clinical picture presented by these patients. Those of us who are associated with children's hospitals, as I happen to be, are also familiar with the large numbers of patients who turn up for relief in the out-patient clinic and in private practice, particularly if one gives them the attention they deserve.

As I understand it, the arch of the foot is maintained by three main factors: first, the shape of the bones and their relation to each other; second, the supporting ligaments; and, third, the supporting muscles. I believe Dr. Harris and Major Beath have shown very clearly that, in a high percentage of children and young adults with flat feet, there is disturbance in the shape of the bones and in their relationship to each other. The relationship of the head of the astragalus to the os calcis is very clearly disturbed in these severe cases.

In searching for a means of overcoming this disability, we have found in a great many cases that conservative measures fail to give relief. We have tried various procedures, including foot exercises, corrective shoes, and the wearing of Whitman plates; but in most instances patients continue to have flat feet which, as time goes on, become a source of serious disability.

Some twenty years ago we were much impressed by the contribution of the late Dr. Michael Hoke to this subject, and were encouraged by the results he obtained by operative treatment. He was of the opinion that the cause of the deformity was a rotation outward of the fore part of the foot at the scaphocuneiform joint, associated with a short tendo achillis. He recommended fusion of the scaphocuneiform joint after correction of the rotation of the fore part of the foot, followed later by a lengthening of the tendo achillis.

We carried out the Hoke procedure on several patients, and were somewhat disappointed in the results obtained. Later, we tried the procedure described by Dr. Kidner of Detroit—namely, a transplantation of the posterior tibial tendon to a new insertion—but here again we felt that, although the feet were improved, the results were not so satisfactory as one might desire. This led us, about sixteen years ago, to a new operative procedure,—namely, arthrodesis of the astragaloscaphoid joint, associated with transplantation of the insertion of the posterior tibial tendon to a new position. We have followed this method since, with very gratifying results.

One other point which I believe to be of considerable importance is the most suitable age at which to submit the patient to operation. Dr. Harris stated that operative interference should be deferred until adolescence or young adult life. Personally, I do not think it is necessary to wait so long, and I believe that these children can be operated upon at ten to twelve years of age with very satisfactory results.

Up to the present, we have reserved the operation for those patients with extremely flat feet. I think we have been too conservative and, as time goes on, we shall be inclined to operate upon more patients with moderate disability.

We have recently made a study of a number of patients, operated upon ten or more years ago, who have now reached adult life. We are greatly impressed with the normal appearance of the feet and with the finding that the patients are able to carry on an active and useful life, without foot disability.

Dr. J. Warren White, Greenville, South Carolina: I have been extremely interested in this subject. I think we all know about the book which Professor Dwight wrote many years ago on variations of the small

bones of the hands and feet, in which he described astragalar variations. I would like to ask Dr. Harris hi opinion about the shortening procedure of the long neck of the astragalus, which I desciibed a few years ago I am still doing it and it seems to be working out quite satisfactorily.

A few words about this elongated neck would appear to be in order, as Dr. Harris has mentioned ana tomical variations of this bone. Others than myself have tried to lay the blame for one type of flat-foot upoi the shape of this bone and the disturbed function of the tendon so closely associated with its head. In shortening the astragalar neck, we are allowing the anterior tibial tendon to function more satisfactorily and, as we saw in the moving pictures, the scaphoid slides back and forth over that projecting astragalar neck. It has a hard time rounding the head, so why should we not shorten the astragalar neck and at the same time change the insertion of the anterior tibial tendon? It does produce a still greater varus of the fore part of the foot, and the insertion of the anterior tibial tendon is displaced farther medially. This is a distinct advantage in giving support for the arch. If, at the same time you shorten the astragalar neck, you go in from the outside and make an osteotomy posterior to the calcaneocuboid joint, you further increase the lateral border and you have a more normally shaped foot. That helps in the correction of congenital valgus of the fore part of the foot. I have found it of considerable value.

I would like to hear what Dr. Harris has to say.

Dr. Compton Riely, Baltimore, Maryland: It has been very interesting to hear these papers, which seem to me very important, because it looks as if we know less about flat-foot than we do about many other things. I shall never forget a visit I made to Dr. Whitman's clinic many years ago. I told him I had difficulty in the treatment of flat-foot. The first question he asked was: "How do you take the impression?" I said I put the foot down in the plaster, obtained a mold, made a cast, and then had a support made over it. He said: "I am going to show you how wrong that is. I have a flat-foot coming in right now." He sat the patient on a seat, flexed and rotated the knee outward, and put the foot around in position to draw the astragalus into line. You remember that Gray and other anatomists state that the normal direction of the astragalus is upward, forward, and out. If the outer extremity of the astragalus is turned up, it throws everything else out of line.

After I went home and took impressions that way, I found that I had entirely different results. He had done away with the valgus of the foot.

We have not only to consider the feet in flat-foot, but also the hip joint, the knee joint, and the toes. In many of the cases shown here this morning, the toes were bound down so that their ends were pressed backward, causing the foot to be abducted; also, in an effort to maintain balance, the knee would be hyperextended.

We all seem to forget that the ends of all long bones have an eccentric action and, if those bones get out of alignment—if you have knock-knee or bowlegs—you have to do something to the bones.

One other great cause of flat-foot, in my opinion, is the wearing of short shoes. In recent years, I have noticed that a great many babies coming into the clinic have short shoes. They do not look short, but the toes of the shoes have been so sloped that it makes the shoe much shorter than the child could wear if the toes had been vertically higher in front. Another very important thing is to have the arch of the shoes at the proper point with the proper pitch, and not too high.

Following the method of Whitman, I have the shoes made and that is all. I do not direct the patients to take any special exercises, only teach them how to walk properly, but I see that the arches are put into the shoes in the proper place. (All manufacturers whose shoes I have looked at, whether for men or for women, have the arches placed too far forward.) If you will take that into consideration, you should have to do few operations.

As for lengthening the tendo achillis, I have done that, but to me the result was not worth while.

Dr. Halford Hallock, New York, N. Y.: This paper has been most important. There are many causes for flat feet and many pathological factors involved. I think the discussions have brought out the fact that we do not know too much about these various causes. The more we find out about them, the sooner we will be in a position to apply intelligent treatment. I would like to emphasize this point in the paper,—that this is another effort toward clarifying the fundamental factors in this entity. A great deal of work has been done by many men on the fundamentals, notably, Hibbs, Hoke, and Dudley Morton, who really began the study of the anatomical variations of the foot and its evolution. Others, however, have been concerned chiefly with the front part of the foot, with relation to the shortness of the anterior segment. Dr. Harris is concerned with the lower portion of the foot. I think the whole foot has to be considered. I am glad to see these factors brought to our consideration, and I hope that other groups will take them up.

I would like to mention one thing for Colonel Harris's benefit, that, in the discussion of abnormalities, nothing was said about the relation of the subtalar portion. Perhaps you would like to include that in a consideration of these anatomical factors.

Colonel Robert I. Harris (closing): It is gratifying and stimulating that our paper upon this ordinary subject should have brought forth so much and such informative discussion. I shall not try to answer all the

(Continued on page 150)

STRUCTURAL PATTERNS OF CALLUS IN FRACTURES OF THE LONG BONES

I. With Reference to Healing after Internal Fixation

BY EDGAR M. BICK, M.D., NEW YORK, N. Y.

From the Orthopaedic Service of Robert K. Lippmann, M.D., The Mount Sinai Hospital, New York City

A broken bone is healed when a complex, but highly specific, histological and biochemical reaction has restored the continuity of its network of mineral-impregnated trabeculae. The newly formed ossific tissue which effects this reconstruction forms a mass, developing at first about the shaft in the vicinity of the fracture, and later invading the fibrous soft callus which had previously bridged the fracture space and united the fragment ends. This ossific mass has been studied intensively from the histological and biochemical viewpoint, but its morphological characteristics have been all but neglected since the classical work of James Paget, early in the nineteenth century. Furthermore, the use of tracings of roentgenograms, taken at repeated intervals, presents a dynamic rather than a static approach to the study of the structural development of the ossific mass, which was not available in Paget's time. Such tracings form a basis for the present study. During this investigation, it became apparent that the ossific mass develops along predictable morphological lines, and that its forms remain uninfluenced by certain factors, but vary in a specific direction with others. Recognizable deviations from these norms were often the earliest indications of extraneous influences, or of probable, if not irreversible, non-union.

The form or pattern of the mass often appears grossly irregular and apparently without design, when examined directly through a wound or surgical incision. However, when its outline is studied by means of tracings of its silhouette made from a good roentgenogram, a remarkably clear picture of a purposeful pattern can be discerned. A series of such tracings was made from a large unselected collection of fractures of the shafts of long bones, treated by standard non-operative methods. From these tracings there evolved a set of regularly repeated patterns, which followed easily recognizable rules. These patterns, after allowance for variations in size and degree of density, and minor variations in contour due to the shadows of the ridges and nodules formed in their development, could be correlated with the type of fracture and the relative position of the fragments during the greater part of the early weeks of immobilization. In these tracings no attempt is made to show the internal architecture of the ossific mass, but rather its structural outline. The variations in density, which occur within the developing mass and are more or less distinctly visible on the roentgenograms, are expressions of differences in the time factor of ossification in different areas. Eventually, a fairly homogeneous density appears in cases with normal healing.

BASIC PATTERNS

Type Pattern

By the end of the sixth week, the periosteal ossific mass in a normally healing fracture of a long bone is a firm structure, reaching from a variable distance on each side of the fracture space and crossing it. Its thickness in reference to the diameter of the shaft varies in circumference and also in its length. It is least at the extreme distances from the fracture site, but not necessarily of greatest depth at that site. Often the periosteal mass is deeper a centimeter or two away from the fracture.

Simplest Pattern

The simplest pattern formed by the ossific mass is that which occurs in fractures near the ends of the shafts of long bones,—that is, through predominantly cancellous tissue

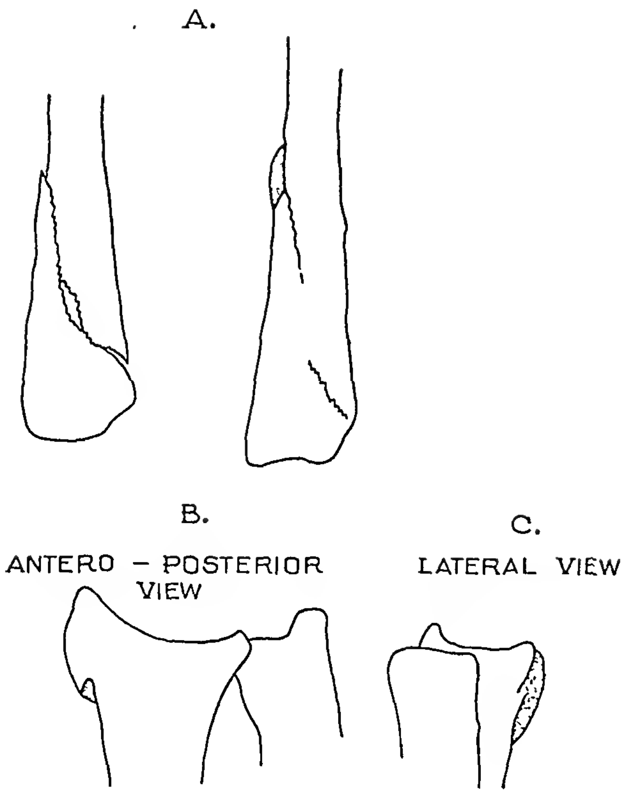

FIG. 1

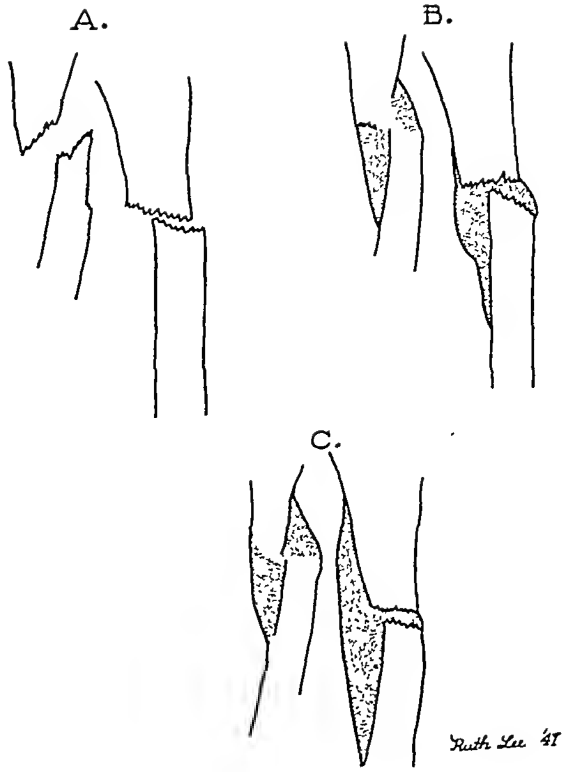

FIG. 2

within thin cortex, in which there is little or no displacement. Figure 1 shows characteristic tracings of two such types: One is a fracture in the lower end of the fibula; the other is the common fracture of the distal end of the radius. Little evidence of an ossific mass appears outside the fracture space, either on the tracing or under direct vision at the operating table. Most of the ossific mass in these cases is internal,—that is, it derives from the endosteum and spongiosa. Since there has been no significant displacement of the axis of the shaft, there is no significant shift in the lines of force to which the fractured bone is subject. The apposition of the fracture surfaces, even though cemented only by the fibrocartilage of soft callus, is such that little external support is required. This slight addition is supplied by the external ossific mass, formed as struts, however small, along lines required by the functional compression force in the long axis of the bone. These struts are constructed relatively rapidly, long before the "fracture line" disappears from the roentgenogram or from histological sections, and are resorbed to a greater or lesser degree, depending upon their functional usefulness, after the fibrocartilage has been replaced by the internal ossific mass. *The volume of the external ossific mass is in direct proportion to the degree of displacement.* In the simplest pattern this is, therefore, minimal.

Patterns Formed with Displacement of Fragments

The patterns more commonly seen are those exhibited in fractures of the shaft between the metaphyseal expansions. Several variants are shown in Figures 2, 3, and 4. Figure 2 is a tracing from the roentgenograms of a fracture of the proximal portion of the shafts of the radius and ulna. The radius was displaced to a degree which left no contact of the fragments, and this position could not be improved. Hence, until such time as the soft callus could be replaced by the ossific mass, a mechanism was required which would temporarily transmit the stresses to which the fracture was being subjected. The most economical means of constructing a temporary brace was to drop an ossific strut from the lateral periphery of the upper fragment to the lateral surface of the lower fragment, reaching as far distal as was necessary to form a relatively straight line of transmission of compression force (Fig. 2,*B*). This is the characteristic pattern of all fractures of the long bones in which there is complete displacement of the fragments of the shaft. In the neigh-

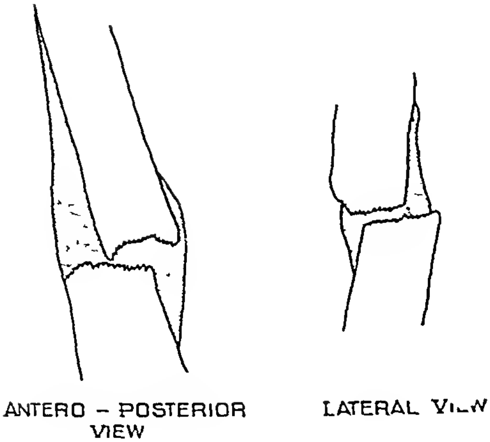

Fig. 3

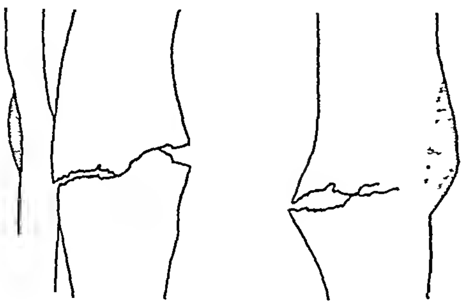

Fig. 5

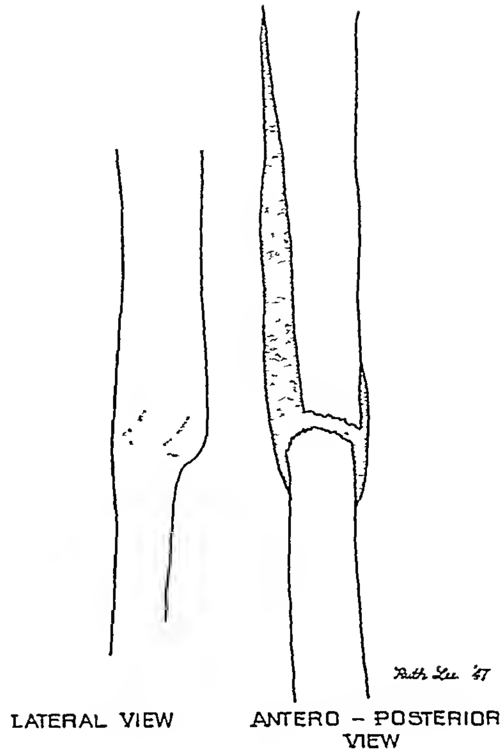

Fig. 4

boring ulna, displacement was not so great, but was about 50 per cent., with moderate angulation. In this situation, the line of force transmission in the lateral half of the cylinder crossed the fracture line, starting from a considerable distance along the distal fragment. As will be seen in Figure 2,*B*, during the development of the strut, the line was dropped from the proximal overhanging ledge to the distal portion of the shaft, which is again the most economical position from a mechanical viewpoint. In this case, as was to be anticipated, the fracture lines were still visible long after effective healing had been manifested by unrestricted function of the limb. The significance of this will be discussed later, but the fact is important in the consideration of the structural pattern.

Figure 3 shows a variation of the same pattern in a femur with partial lateral displacement and some angulation. Here again, in the anteroposterior view, is seen an ossific mass, large enough to be a prolongation of the lateral surface of the lower fragment in an almost straight line. On the medial surface appears a smaller strut to brace the overlapping medial periphery of the end of the upper fragment. The lateral view shows some displacement, but no significant angulation. It is obvious, when viewed mechanically, that at this point very simple and small struts are required; and such were constructed. In Figure 4 is traced the common fracture at the juncture of the middle and lower thirds of the tibia in a case where healing was normal in average time. In this case, a narrow band of the ossific mass can be seen in the lateral view. This narrow and unilaterally prolonged ossific mass is another variant of the patterns seen in Figures 2 and 3, and is characteristic of many transverse fractures of the tibia at this level with little displacement. In poor roentgenograms, or when the films are examined too casually, this type of case is often referred to as showing little callus. This stems from the common misinterpretation of the function of the external ossific mass as a welding material. Actually, when this pattern is examined from the points of view presented here—that is, the mechanical requirements for transmission of compression along the normal lines of force of the tibia—it will become apparent that no more callus is necessary.

These typical patterns were repeated regularly in all roentgenograms examined of cases in which healing was known to have been normal, and varied only enough to fulfill mechanical demands.

Discussion

It may be said, therefore, that the pattern of the external mass of any fractured bone represents the most economical structure which *will serve as a rigid line of transmission for* the stresses and strains normal to that bone in its long axis, until such time as osseous continuity through the fracture line has been restored. The mass appears first as a partially circumferential strut involving the periosteum, and remains in this position until internal healing is complete. The quantitative distribution of the mass about the shaft—that is, the external portion of the mass—will be conditioned solely by the mechanical requirements of the displacement of the fragments. These patterns are characteristic and vary in a normal case only with the position of the fragments. The external portion of the mass does not ordinarily exhibit a "welding" process. It is not structurally an essential part of the union, which takes place far more slowly within the fracture space, except in so far as its tissues later invade this space and contribute osteogenic elements to it. Furthermore, the external mass is to a greater or lesser degree absorbed after osseous continuity of the shaft has been re-established. While its form superficially may appear to conform to Wolff's law, it is fundamentally not in accordance with it. Wolff's law refers to a remodeling of the architecture of the healed bone in response to function. The pattern of the external ossific mass is an external strut or brace which temporarily holds two or more fragments in position, and transmits stresses outside the direct line of the axis. Wolff's law may operate later in the healed fracture, to restore direct alignment of the trabeculae of a deviated shaft. If part of the external ossific mass is required for this purpose during the remodeling period, that part may be retained, as the residue of the external mass is absorbed.

The patterns of the ossific mass appear to result from a reaction conditioned by physical factors of stress and strain, a fact recognized long ago in Paget's concept of "design". In an uncomplicated case, very little of this osteogenic material is wasted. The ossific mass, when completed, does not extend externally beyond the lines which can, within a very small margin of error, be anticipated. The ossific mass does not "enlarge" or "grow" from a single original center of deposition or from symmetrical centers. It may appear first as a narrow line along the shaft, some distance from the fracture line; or it may, as in Figure 2, appear first as a small node near the line. As the mass develops, separate centers rise asymmetrically, simultaneously or in sequence, and finally merge. However, no such center, in a case with uncomplicated healing, appears at a false point,—that is, it never appears more widely dispersed or at a greater distance from the fracture than will be necessary to form the mechanically required strut. The formation of the external portion of the ossific mass may be compared in certain respects to the temporary structures used in construction work to brace bridges or roofs while the original beams are being replaced or strengthened. While held by these ossific struts, physiological resorption and replacement of the bone ends of the fragments can proceed as part of the process of reparative osteogenesis, without collapse of the fracture space.

FACTORS GOVERNING THE EXTERNAL CONFORMATION OF THE PATTERN

Factors Inherent in the Trauma

1. *Influence of Periosteum:* An observation first brought to general notice by Paget is particularly pertinent to this discussion. Describing human fractures of long bones, he stated that periosteum is rarely much damaged, seldom stripped from the fracture line, and often remains remarkably adherent to the bone, "even in extensive fractures". The author does not recall seeing this noted elsewhere, and, in fact, has heard the contrary view stated many times. It has been taught repeatedly, on the one hand, that excess callus forms under

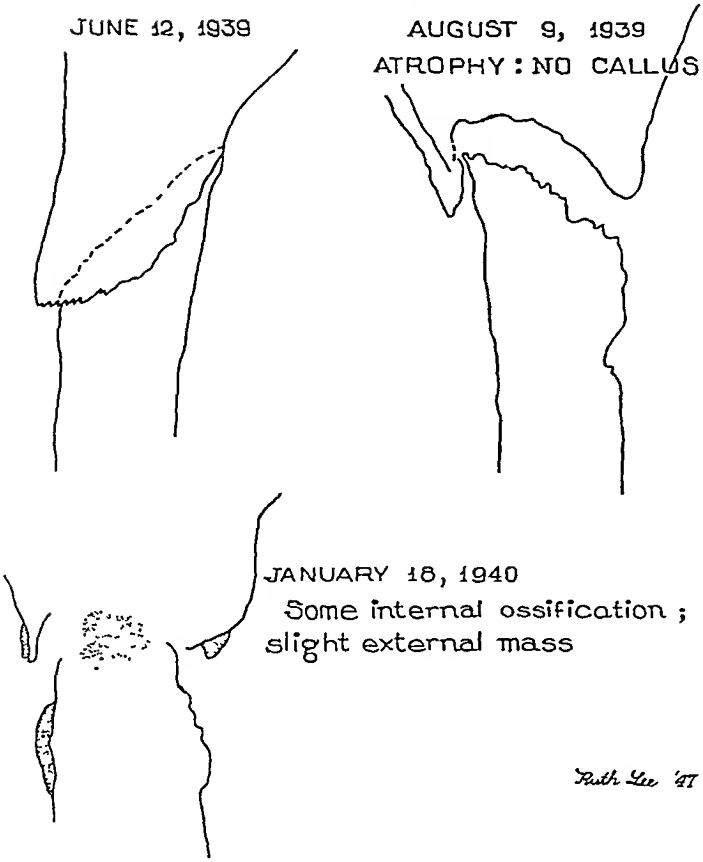

FIG. 6

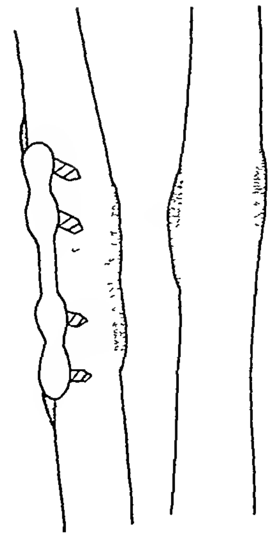

FIG. 8

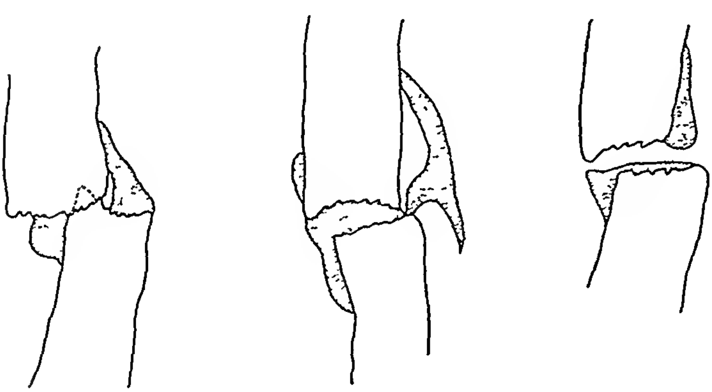

FIG. 7

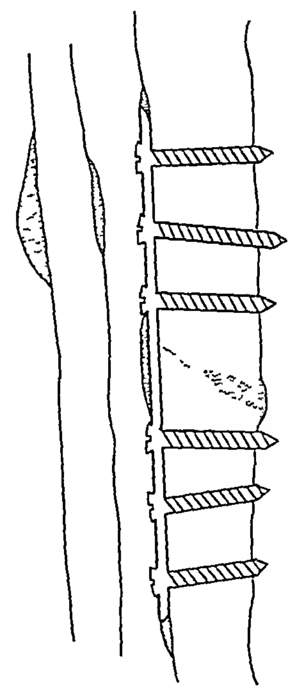

FIG. 9

he surface of stripped periosteum, and, on the other hand, that stripping of the membrane rom the surface of the bone prevents callus formation. Neither of these two statements can e supported by direct observation. Paget's remarks proved surprisingly true in the many ases of severe open fractures seen abroad during the years of World War II. As he noted, here was far more often a tear at the fracture site, with periosteum remaining adherent o the cortex even of the comminuted fragments. Lacerated periosteum along the adjacent shaft was common enough; periosteal stripping of a centimeter or more was rare. Regardless of the appearance of the periosteum, the structure of the external mass developed in uncomplicated cases as the position of the fragments dictated. Even in certain cases of open fracture with large wounds in which, for various reasons, excessive callus formed subsequently, no significant detachment of the periosteum had been noted at the time of

the primary surgery. In cases of transverse, uncomminuted fractures of the femur, callus often reached fifteen centimeters (six inches) or more above the fracture site in the demonstrated presence of periosteum which was intact beyond the fracture line. In fact, the pattern of the ossific mass cannot be related to the degree of stripping of the periosteum or to the extent of its laceration.

2. *Fracture Hematoma:* A second factor which at times has been credited with influencing the extent of callus formation is the fracture hematoma. While the hematoma within the fracture space may or may not be an integral part of the soft callus, its importance to the formation of the ossific tissue of bone healing has been at times obviously overestimated. The development of a normal, or even extensive, external mass, in cases from which the blood had been immediately drained from the fracture area through large debrided shell-fragment wounds, precluded the possibility of any important relationship between hematoma and bone formation. It has been said that in such cases a secondary hematoma, derived from the intra-osseous circulation, replaces that of the original trauma. This is sometimes true within the fracture space. However, during the early part of the War, before delayed primary suture of wounds had been introduced, certain open wounds required repeated dressing because of resistant infection. Secondary hematomata did not collect within these wounds to any extent comparable to the excessive external callus often found in patients suffering a low-grade traumatic osteomyelitis. Furthermore, the earliest development of the external ossific mass often appears in the periosteum, several centimeters away from the fracture space, at levels which are demonstrably not within the sphere of a small hematoma. In brief, the concept of Stirling that callus in general is formed within a "shut-off chemical factory" is simply untenable. Certainly it cannot be demonstrated that the extent of hematoma bears any relation to the quantity of structural form of the ossific mass, and considerable observational evidence at the operating table indicates that it has no influence whatsoever on its development.

EFFECT OF TREATMENT ON PATTERN OF THE OSSIFIC MASS

Non-Operative Treatment

In all of the cases reviewed for this study, an attempt was made to define a possible relationship between the method of treatment and the pattern of the resulting ossific mass. (The time factor or relative efficiency of the method is not of concern in this study, which relates solely to the form of the mass in normally healing bone.) Closed methods of treatment of fractures of the shafts of long bones fall into two primary categories, traction or immobilization, the latter usually by plaster.* Each of these primary methods is subject to variations which attempt to solve local anatomical problems, but do not significantly modify the mechanical principles involved. One special group, fractures of the humerus, treated by the technique of the hanging cast, may be considered a combination of traction and immobilization. The same may be said for a few examples of another technique used in combined fractures of the tibia and fibula,—the double-pin plaster technique.

The success of immobilization or reduction and the efficiency with which the corrected position was maintained varied considerably with the type and location of the fracture, and with the method used; but the pattern of the ossific mass in each case known to have had normal healing reflected the position of the fragments during the period of formation of the mass, and bore no determinable relationship to any other factor.

These observations apply to fractures proceeding to normal healing. Structural evidence of impending non-union may appear at any time during the development of the ossific mass. The mass may appear in minimal or inadequate quantity (Fig. 5); it may develop either above or below the fracture site alone (Fig. 6); or it may appear unequally on both fragments and fail to cross the fracture line. Its variations are many. It may

* Patients treated during the healing stage by traction and later maintained in plaster were obviously considered traction cases.

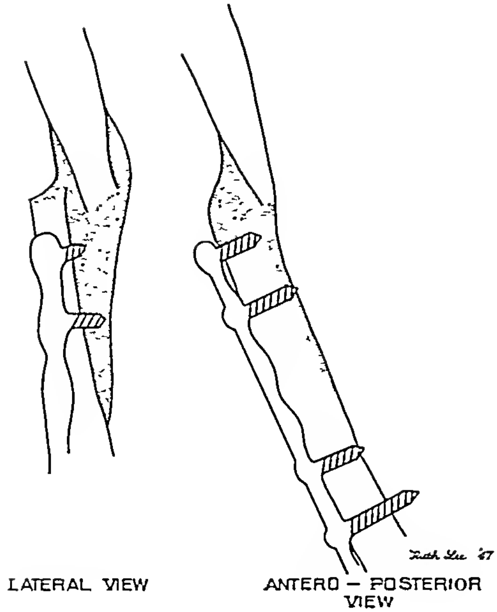

Fig. 10

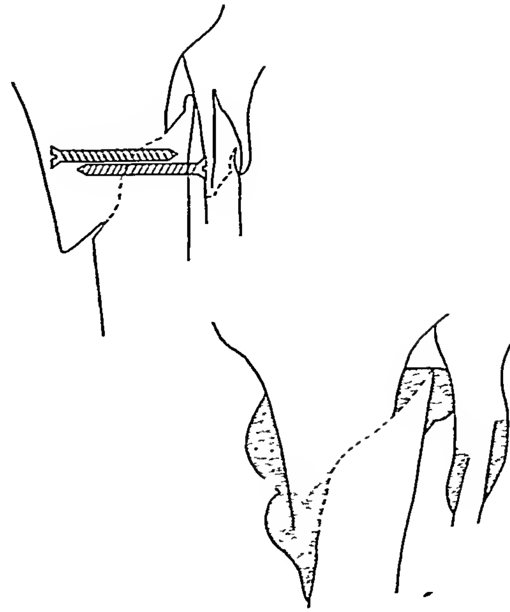

Fig. 11

develop apparently normally and, for some reason still unknown, be found involuting after a period of arrest (Fig. 7). On the other hand, low-grade infection following open fracture often acts as though it were a stimulus to excessive osteogenesis; but the mass in these cases does not develop normal patterns, and its quantity is never a guarantee that continuity will be restored between fragments.

Effect of Internal Fixation

A common source of uncertainty in gauging the results of fractures of the long bones, treated by internal fixation, is the difficulty in determining the time of effective bone healing. Experience has repeatedly demonstrated that, following internal fixation, effective stability in the healing bone may be obtained long before roentgenograms give evidence of those criteria of union which are ordinarily sought for in cases treated by other methods. The patterns of the mass are not those described in the preceding sections. Failure to appreciate this fact, or timidity in trusting its implications, has led too often to unnecessarily prolonged immobilization, and has thereby delayed the beneficial effects which earlier activity might have afforded.

It is a matter of common knowledge that the more accurately the fragments of a fractured shaft of a long bone are aligned, and the more efficiently they can be immobilized in good position, in the absence of extrinsic irritant factors such as infection, the less will be the quantity of the external ossific mass. This was demonstrated in the preceding sections, and may be related to the description of the simplest pattern. These two objectives are most precisely accomplished when fracture surfaces can be brought into hairline apposition at the operating table, and can be fixed rigidly by a plate or screw whose firmness will be maintained for six weeks or more. The rigid metal then takes over the temporary bracing function of the external mass to a greater or less extent, depending upon the mechanical soundness of its position relative to the fracture line and the efficiency of its application. Therefore, the ossific tissue which forms the external callus, visible on the roentgenogram, develops to a minimal degree in fractures properly treated by internal fixation, because greater quantity is not functionally demanded. Figures 8 and 9 show the characteristic appearance of the external ossific mass produced in well-fixed fractures of (1) the radius and ulna and (2) the tibia. Figures 10, 11, and 12 are tracings from cases which demonstrate that a plentiful supply of external ossific tissue will appear about the

fracture site, whenever its presence is functionally required because of poor or inadequate fixation. Therefore, the mere presence of rigid fixation does not in itself prevent or depress the formation of the mass. The apparatus must be placed efficiently if it is to take over the function of the external mass and make its appearance unnecessary.

Besides the frequent lack of an anticipated quantity of visible callus in these cases, a second factor contributes to the difficulty of estimating healing time. That is the interpretation of the significance of persisting translucent lines or areas along or adjacent to the original fracture line, visible on the roentgenogram. They are often attributed to any one of three possible defects,—distraction of the fragments, failure of callus formation, or the inability of the fragment ends to become impacted, following the bone necrosis of the fracture surface which is normal to this area in a healing fracture. Often the plate is blamed

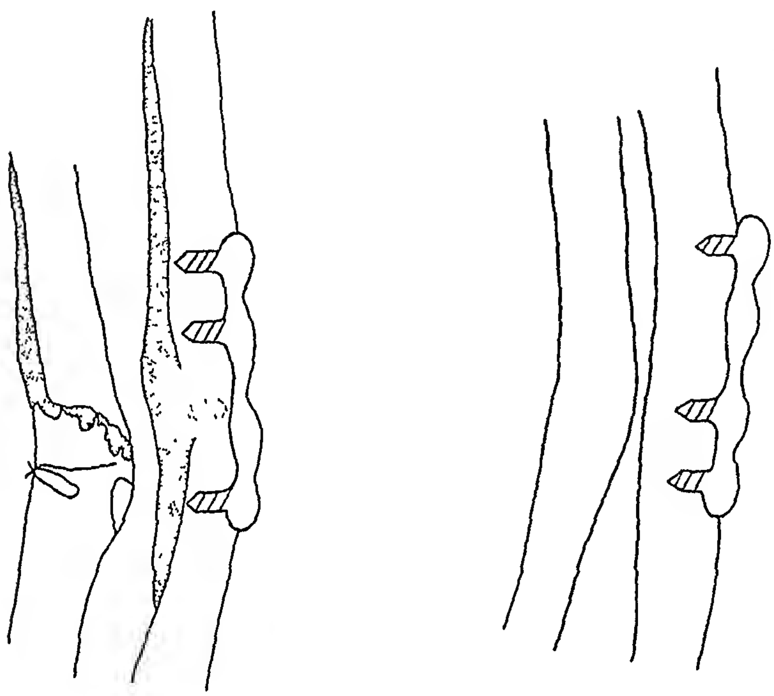

Fig. 12

Fig. 13-A

Fig. 12: Tracings made eight weeks (left) and one year (right) after fixation.
Fig. 13-A: Eight months after insertion of Vitallium plate, insufficient callus was present.

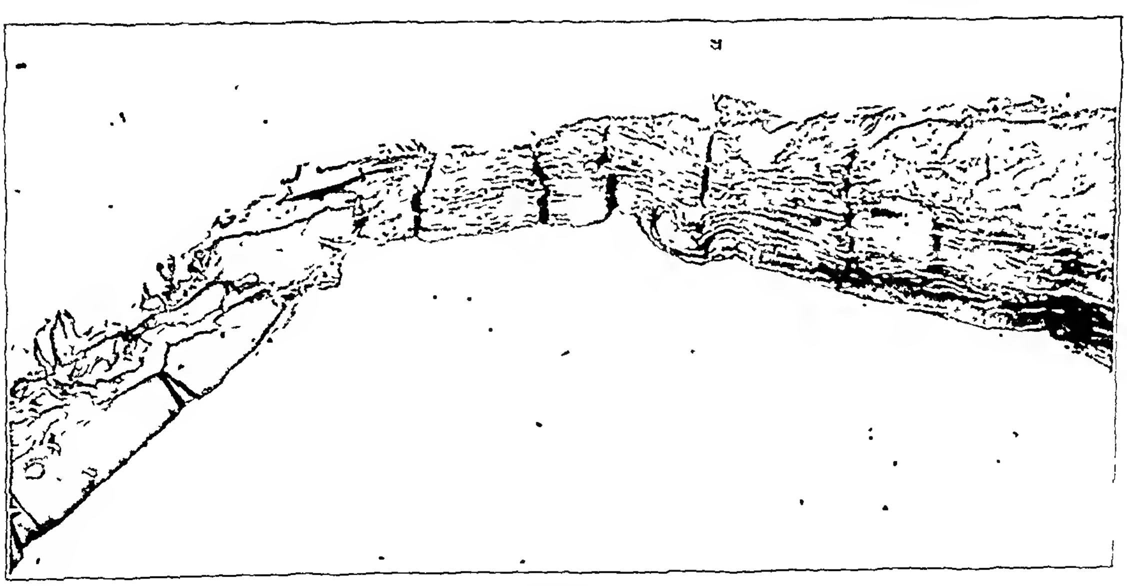

Fig. 13-B

Photomicrograph of section taken at the fracture line of case shown in Fig. 13-A. The trabeculae of the external ossific mass approach, but do not cross, the fracture line.

for having prevented the impaction of the fragment ends. The misinterpretation of such a translucent area has on several occasions, in the writer's experience, led erroneously to secondary operation for suspected delayed union.

CASE REPORT

A woman, aged fifty-four, had sustained a severe closed fracture at the juncture of the upper and middle thirds of the tibia and fibula on April 12, 1945. Because other methods of treatment were ineffective, a six-screw Vitallium plate was inserted on May 3, 1945. Eight months later, the patient was still walking with difficulty in plaster and by the use of crutches, and roentgenograms showed what was considered to be insufficient callus, either external or across the fracture line (Fig. 13-A). It was decided to investigate the fracture with a view to applying a bone graft. At operation, after the plate had been removed, the bone was found to be firmly united. The external mass was represented by a thin shell, reaching approximately the length of the plate. A strip of this, removed for histological examination, showed thin bands of osteoid which approached, but did not cross, the fracture line (Fig. 13-B). No tissue for examination was removed from between the fragment ends, for fear of weakening the union. Its obvious solidity against manual stress was sufficient evidence of effective healing. Following this, the patient remained in bed for two weeks to permit the wound to heal. She was then tested functionally by being urged to bear weight in a walking-iron plaster boot. After a few weeks, since no deformity occurred in the bone, the plaster was removed and unrestricted weight-bearing was encouraged. Because of the prolonged period of restraint, this was difficult for the patient. However, she persisted, and follow-up examination has demonstrated increased density of the fracture site and no subsequent deformity.

COMMENT

The retarded appearance of visible ossification across the fracture space is due to two factors,—one apparent, the other real. The dense shadow ordinarily superimposed over this area by the external ossific mass seen in healing, non-fixed fractures is missing in these cases. In addition, ossific replacement of the soft callus here comes almost entirely from the endosteum and cancellous trabeculae. The customary contribution which permeates the fracture space from the external mass, usually the most rapidly formed, is either absent or minimal. At present, the point in time at which replacement of soft callus by the ossific mass is sufficient to establish effective healing can only be determined grossly by personal experience. Theoretical considerations aside, experience has shown that it is a disservice to the patient, and possibly a deterrent to the later remodeling phase of reparative osteogenesis, to withhold activity or weight-bearing until the translucence of the fracture line has entirely disappeared.

Until some mechanical determinant of resistance to stress and strain is devised which can be applied to the living limb, effective healing must remain a matter of judgment rather than a matter of fact. The cases studied have demonstrated certain observations in restrospect. Our timidity was greater, and consequently the morbidity period of patients following internal fixation was longer, during the earlier years on this Service. As confidence was gained in the use of functional tests with walking irons or crutches, or, in the upper extremity, with guarded activity under observation, morbidity decreased in spite of persistent difficulty with roentgenographic interpretation.

These observations on the pattern of the ossific mass apply only to cases in which internal fixation was efficient,—that is, cases in which full apposition of the fracture surfaces was possible; and screws or plates were inserted in normal bone tissue with correct technique, and were placed in positions which were mechanically sound for the purpose. These principles do not apply when such requirements are not met, as is the case when comminution is extensive, or when the time lag between fracture and operation permits the development of secondary changes on the fracture surfaces. In these latter instances, experience has shown that the criteria of bone healing, as manifested on the roentgenogram, must be those applied to fractures which are not operated upon, and that the density and degree of the external ossific mass are the safest measures of healing. Obviously the

patterns formed are irregular and cannot be presented as types. They are a composite (those required by displacement and by partial fixation.

NOTE: Abou D. Pollack, M.D., of the Department of Pathology, Mount Sinai Hospital, was kind enoug to review with the author the histological specimens used in this study.

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HYPERMOBILE FLAT-FOOT WITH SHORT TENDO ACHILLIS

DISCUSSION

(Continued from page 140)

various items. Much of the discussion has centered about treatment, particularly operative treatment. We deliberately avoided discussion of treatment in our presentation, because we wished to emphasize certain other aspects of the problem: first, that the foot problem is greatly in need of informed study; second, that we lack definite knowledge of the nature of flat feet; and third, that we should seek the important facts which will broaden our knowledge of flat feet. Lacking accurate knowledge, we are prone to resort to hypotheses and, after we have used a hypothesis two or three times, we nearly convince ourselves that it is true and a fact, and then we do not worry to seek facts which will support it.

Further, we wished to emphasize such information as we have been able to obtain by our study regarding the importance of the structure of the foot in maintaining its shape, and particularly in providing support for the rest of the body. Treatment is a broad subject in this kind of flat-foot because, first of all, it is a lesion that is present throughout life. Second, it is a lesion that varies greatly in its severity. There are trivial cases, moderately severe cases, and very severe cases. Third, it produces a varying amount of disability from decade to decade. It bothers the child but little; it bothers the parents more. In adolescence it begins to give trouble. In young adult life it bothers the young man considerably, and certainly it interferes with his function as a soldier. In older life it makes the patient modify his way of living. Therefore, one cannot be dogmatic about treatment, so we purposely avoided a discussion of treatment in our paper. We think surgical treatment should be used in the severe cases, and that it should be used as early as possible without producing serious trouble. We have an operation, similar to the one Dr. McDonald described, which we have been using and which we think is good.

The study in the Canadian Army, from which much of this information was obtained, was very much broader than this particular problem, as it included all foot problems of men in military training. It was of value in determining what the foot problems were in a certain cross section of the male population in Canada, in what numbers they occurred, and what they meant for these young men as soldiers. Should anyone like to read the report of this study, it will be published shortly by the National Research Council of Canada. It is not very easy reading, but it does contain an enormous amount of observed facts, and it may be of value in the estimation of these problems.

CYST-LIKE LESIONS OF CARPAL BONES, ASSOCIATED WITH UNUNITED FRACTURES, ASEPTIC NECROSIS, AND TRAUMATIC ARTHRITIS

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From the Department of Surgery, University of Chicago, Chicago

It is a matter of common knowledge that cyst-like areas of bone absorption occur about the hip in degenerative conditions of the joint. These are seen in malum coxae senilis, but have also been observed following fractures of the femoral neck and traumatic dislocations of the hip, which produce necrosis of the femoral head; in Legg-Perthes disease; and in epiphyseolysis. Similar areas of bone absorption have been observed in many instances about joints, other than the hip joint, that are the seat of degenerative disease.

Few references to the occurrence of such lesions about the wrist, in degenerative conditions of the radiocarpal and carpal joints, are to be found in medical literature, although such lesions are not uncommon. Bunnell, in the section of his book devoted to traumatic degeneration of carpal bones, presents roentgenograms of cyst-like areas in the scaphoid, lunate, capitate, and triangular. In each case, trauma appears to have been antecedent to the onset of symptoms in the wrist. Bunnell seems to favor the theory that there has been a disturbance of the blood supply to the affected bones.

The histories of three patients with such lesions of the carpal bones, who were operated upon at the University of Chicago Clinics, are presented:

CASE 1. O. T., a meat cutter, aged fifty-eight, was first seen in the Clinics on March 1, 1937, complaining of pain and swelling of the right wrist, which had been present for from four to five weeks. No injury was remembered, but, for from ten to twelve years, this wrist had been thicker than the other. The patient was right-handed and had used a cleaver steadily at his work. Physical examination showed that the right wrist was one centimeter greater in circumference than the left. There was no limitation of motion in the wrist, but slight grating was noted. Laboratory examinations, including the Kahn test, were negative. Roentgenograms of the wrist (Fig. 1-A) showed a large cyst-like area of central absorption in the capitate, and a smaller area in the triangular. There was no sclerosis of the surrounding shell of bone. The cartilage of the radionavicular articulation was narrowed, and the cortex of the bones was obscured. At operation on May 20, 1937,

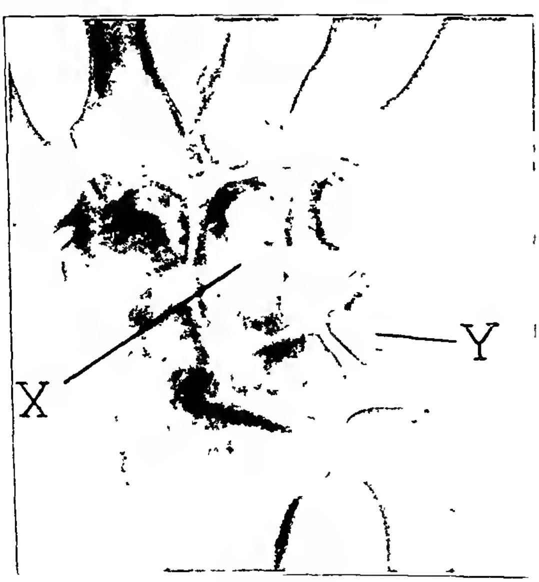

FIG. 1-A

FIG. 1-B

Fig. 1-A: Case 1, O. T. Aseptic necrosis and central absorption of capitate, X. Central absorption in triangular, Y. Chronic arthritis in wrist with narrowing of cartilage space between radius and navicular.

Fig. 1-B: Views of the excised proximal portion of the capitate.

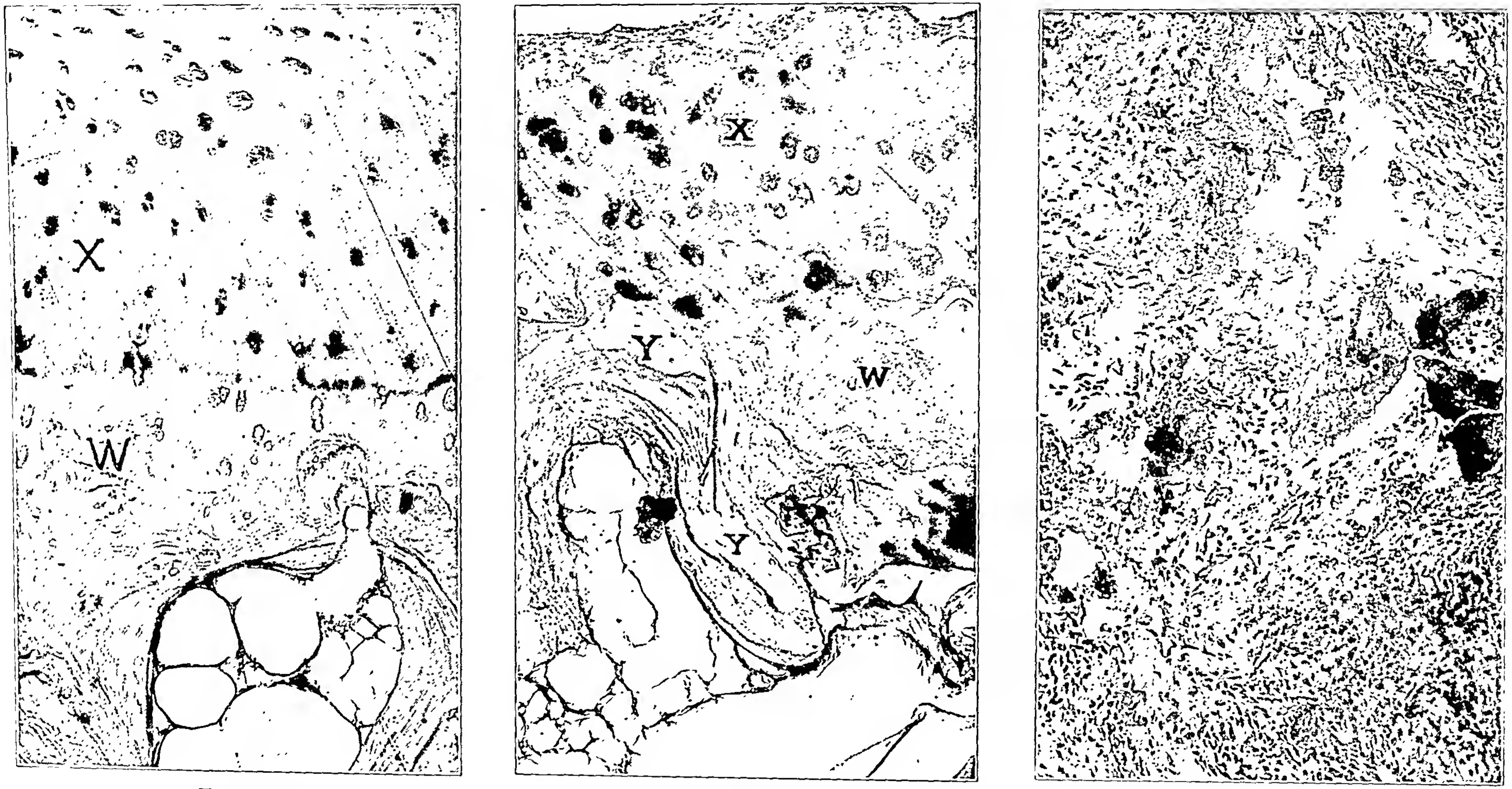

Fig. 1-C Fig. 1-D Fig. 1-E

Microscopic sections of excised portions of capitate.
Fig. 1-C: Cortex with necrotic bone, *W*, and feebly staining articular cartilage, *X*.
Fig. 1-D: Region of cortex undergoing creeping substitution. Cartilage, *X*, being replaced by fibrocartilage, and dead bone, *W*, being replaced by new bone, *Y*.
Fig. 1-E: Fibrous tissue, *Z*, which occupied central portion of capitate, is partly calcified.

the capitate was exposed through a dorsal incision, and an old fracture, with a narrow line, was found in the cortex at the margin of the proximal articular cartilage. It had obviously occurred secondarily, *after* central absorption of the bone. A window was excised, which exposed a large cavity filled with fibrous tissue, yellowish necrotic material, and a small amount of fluid. The contents were curetted out. Inspection of the proximal articular surface revealad that it was yellowed, mottled, and apparently dead. The dorsal part of the proximal end of the bone was, therefore, removed (Fig. 1-B), and the wound was closed. Smears of the joint fluid showed many polymorphonuclear cells and lymphocytes. Cultures of this fluid showed a growth of *Staphylococcus albus* after forty-eight hours. This was probably a contaminant, since cultures of fluid from the cyst showed no growth. Guinea pigs inoculated with fluid and necrotic tissue from the cyst showed no evidence of tuberculosis. Microscopic sections of the excised tissue (Figs. 1-C, 1-D, and 1-E) showed that the cyst was occupied by partially necrotic and calcified tissue. The shell of bone surrounding it consisted, in part, of necrotic trabeculae, which were undergoing replacement by new bone in some areas. The articular cartilage of the excised proximal fragment of bone stained poorly; it had been partially replaced by fibrocartilage. The bone underlying this cartilage was necrotic. A portion excised from the anteroproximal part of the capitate showed living bone, covered by fibrocartilage. The postoperative course of the patient was uneventful. A splint was worn for four weeks. The patient returned to work two months after the operation, with the wrist practically free from pain and two thirds of the normal motion present. He has continued to work, but has avoided strenuous use of the hand, and has had no further difficulty. Figure 1-F shows the condition of the wrist three years after the operation.

FIG. 1-F

Three years after Fig. 1-A. Wrist is symptom free. Arthritic changes in radionavicular joint. Cavity, *Y*, persists in triangular.

CASE 2. G. H., a housewife, aged fifty-seven, was first seen in the Clinics on April 4, 1944, complaining of intermittent periods of pain and swelling of the left wrist, which had been present since a fall on the outstretched hand thirty years before. There was pain and swelling for some time following the original injury, but no medical attention was sought. Subsequently, too active use of the hand resulted in recurrences of pain and swelling of the wrist. Physical examination revealed swelling over the dorsum of the wrist and marked limitation of motion. Roentgenograms (Fig. 2-A) showed a cyst-like area, without sclerosis about it, occupying the proximal two thirds of the capitate. The navicular was in two parts; the proximal part was narrowed and deformed. There were well-developed degenerative changes in the radiocarpal joint. A fracture of the navicular appeared, therefore, to have occurred, with aseptic necrosis of the proximal fragment: nonunion; subsequent collapse of the fragment, and its transformation; and secondary arthritis. Laboratory examinations were negative. At operation on April 14, 1944, a partial ostectomy of the capitate and curettage of the cyst were done through a dorsal exposure. Microscopic examination of the excised tissue (Figs. 2-C and 2-D) showed that the cyst was lined by fibrous tissue of varying cellularity. Bits of bone were found in the fibrous tissue. The surrounding bony trabeculae were for the most part normal, although there were a few subcortical areas of dead bone being replaced by living bone. The articular cartilage showed degenerative changes, with extensive replacement by fibrocartilage and fibrous tissue. A plaster splint was applied to the wrist, following the operation, and was worn for four weeks. The wound healed promptly. Considerable restriction of motion in the wrist persisted, but function improved. One of the roentgenograms, taken two months after the operation, is shown in Figure 2-B.

CASE 3. H. W., a steamfitter, aged thirty-five, was first seen in the Clinics on January 9, 1946, complaining of intermittent pain in the right wrist, which had been present since an injury incurred in a football game twenty-one years before. The wrist was swollen and painful after the injury, but symptoms subsided in a few weeks, to become aggravated again whenever hard work was done. Roentgenograms had been taken in 1913, and these showed that the navicular was in two parts, but there was no evidence of necrosis of the

proximal fragment. There was cystic rarefaction of the lunate, with a shell of sclerotic bone about the cyst. A small loose body was seen near the navicular, and there were tiny osteophytes along the articular surface of the radius. Roentgenograms, taken at the time of admission to the Hospital (Fig. 3-A), were essentially similar to the earlier roentgenograms. Physical examination showed slight swelling of the wrist, weakness of grip, and pain on hyperflexion and hyperextension of the wrist. The blood Kahn test was negative, as were other laboratory examinations. At operation, the lunate and navicular were exposed through a dorsal incision. The synovial lining was hypertrophied. A pedunculated osteocartilaginous loose body was removed from the junction of the lunate and capitate. The fragments of the navicular appeared to be viable, and were not disturbed. The cyst of the lunate was opened. It contained a small amount of fluid and a large amount of fibrous tissue, which was removed with a curette. Cultures of the fluid from the cyst showed no growth. Microscopic sections of the excised tissue (Figs. 3-D and 3-E) showed that the bony trabeculae in the wall of the cyst were for the most part necrotic. The fibrous tissue of the cavity was also extensively necrotic, and small areas of calcification were evident. The wrist was immobilized in a plaster cast for four weeks after the operation. One of the roentgenograms taken three and one-quarter months after the operation is shown in Figure 3-B. A roentgenogram taken ten months after the operation (Fig. 3-C) showed persistence of the defect in the lunate. The area of reduced density in the proximal half of the capitate appeared to be a trabecular configuration, but may have been a new cyst. When these roentgenograms were taken, the wrist was entirely painless, and a full range of motion was present.

DISCUSSION

In two of the three cases here presented, symptoms dated from an injury to the wrist, and in each there was an ununited fracture of the navicular of long standing. In Case 2, necrosis of the proximal fragment of the navicular, with subsequent collapse or compression, had evidently occurred. In each case, sufficient time had elapsed for advanced revascularization and replacement of the necrotic bone. In Case 1, which involved the capitate, there was no definite history of injury, but the man was a meat cutter, and repeated small traumata of the bone had probably occurred. In all three, there was histological evidence of aseptic necrosis in the shell of bone about the cyst. Factors other than trauma may play a role in the etiology.

The changes undergone by necrotic bone and cartilage, following interruption of the blood supply to the head of the femur, have been described by Axhausen, Phemister,

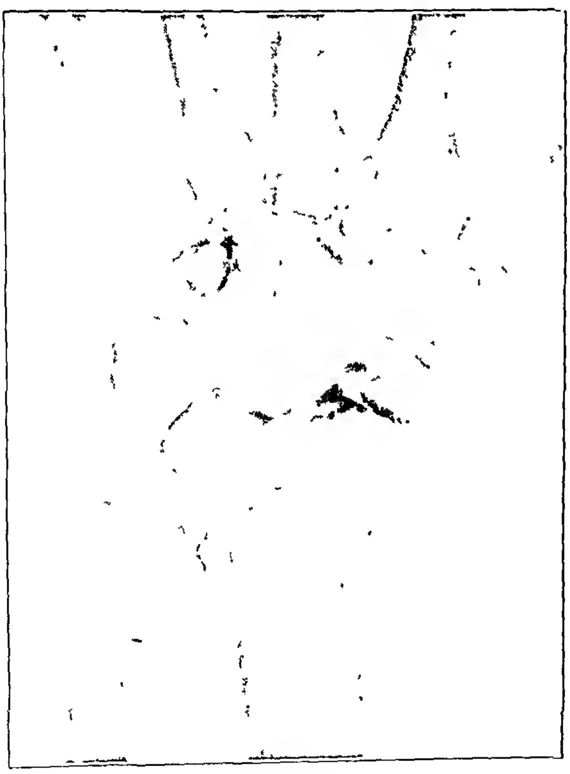

FIG. 2-A

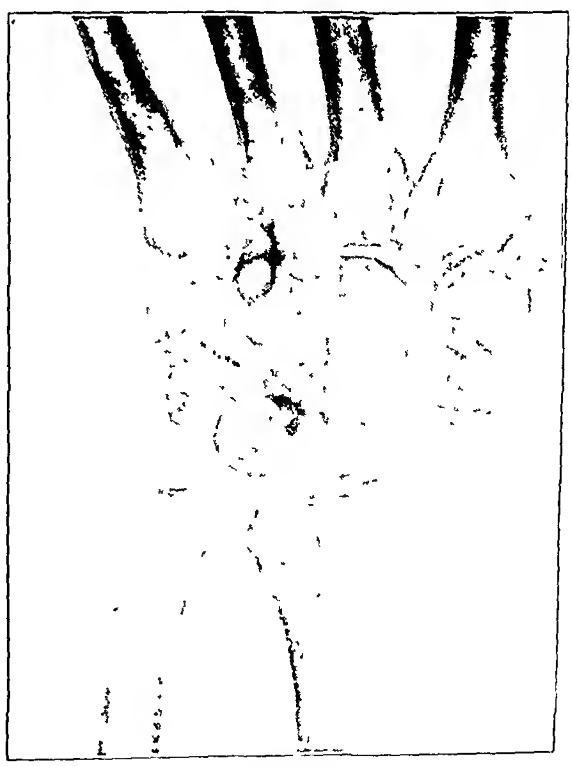

FIG. 2-B

Fig. 2-A: Case 2, G. H. Area of central absorption in the capitate. Old ununited fracture of the navicular. Arthritic changes in the radionavicular joint.
Fig. 2-B: Two months after Fig. 2-A, and after partial excision of the capitate.

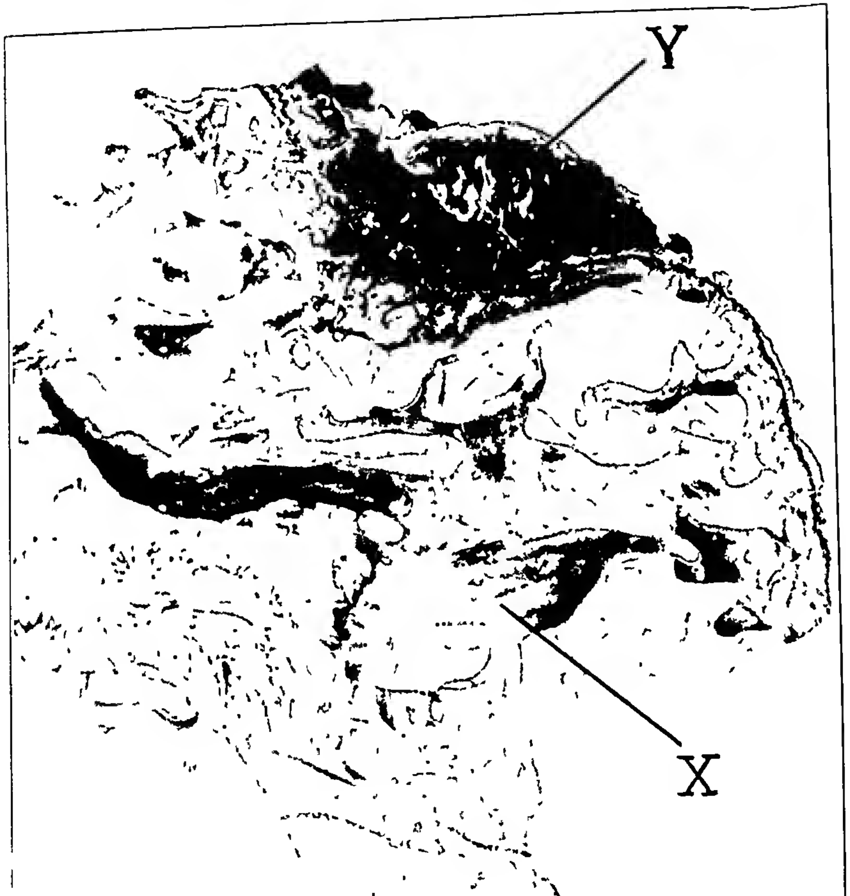

FIG. 2-C

FIG. 2-D

Microscopic sections of the excised portions of the capitate.
Fig. 2-C: Wall of cyst-like area, showing trabeculae of bone, *X*; degenerating cartilage, *Y*; and fibrous tissue, filling defect in bone.
Fig. 2-D: Fibrous tissue from area of bone absorption, with small fragment of necrotic bone, *Z*.

and others. The necrotic epiphysis may undergo progressive and complete replacement by living bone. Usually, replacement is irregular and incomplete. Areas of necrotic bone may be absorbed and replaced by fibrous tissue, without subsequent replacement by living bone. These are the cysts seen late in the process. Articular cartilage degenerates and is replaced to a varying degree by fibrocartilage and fibrous tissue.

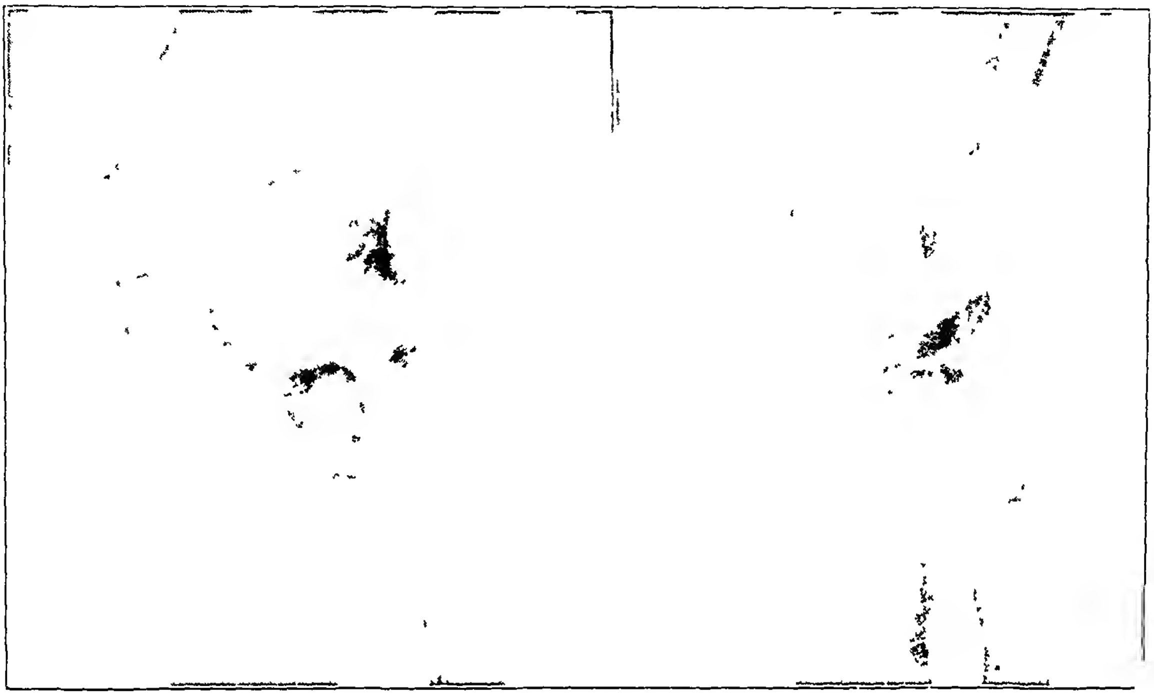

Fig. 3-A

Case 3, H. W. Aseptic necrosis and central absorption of lunate. Old ununited fracture of the navicular. Roentgenograms taken three years before showed same changes.

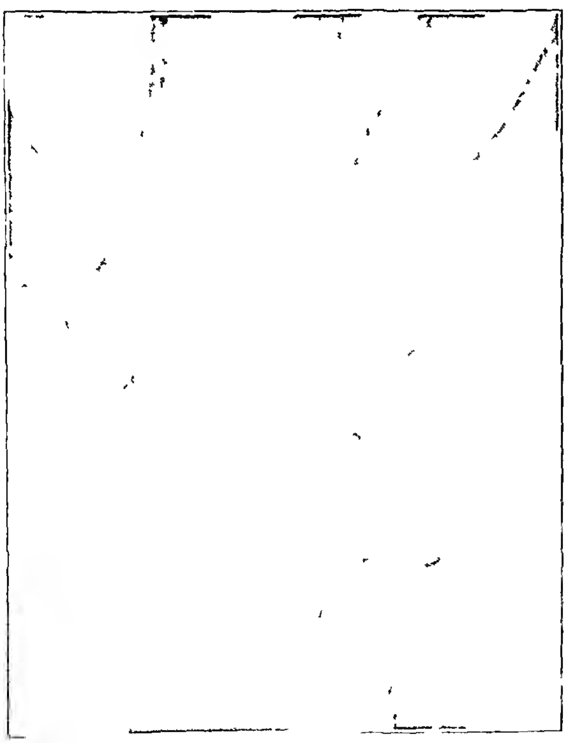

Fig. 3-B

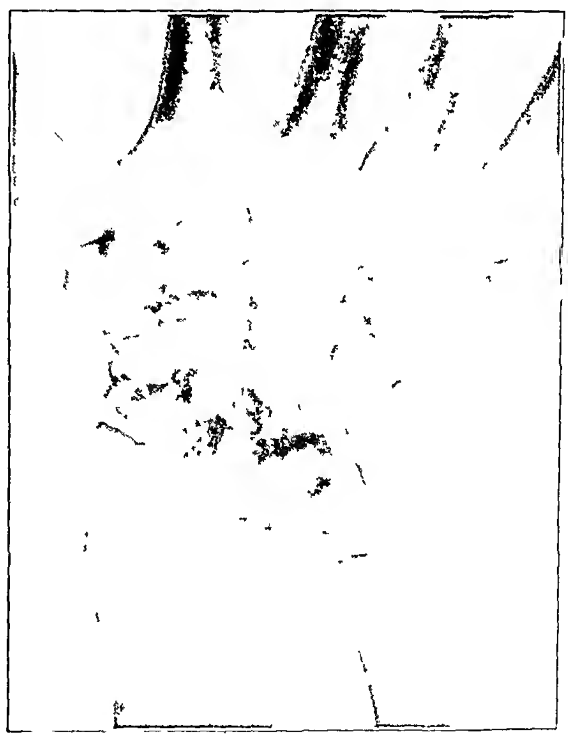

Fig. 3-C

Fig. 3-B: Four months after Fig. 3-A, and three and one-quarter months after excision of dorsal window and curettage of the lunate. Wrist is symptom free.
Fig. 3-C: Ten months after operation. Wrist is painless.

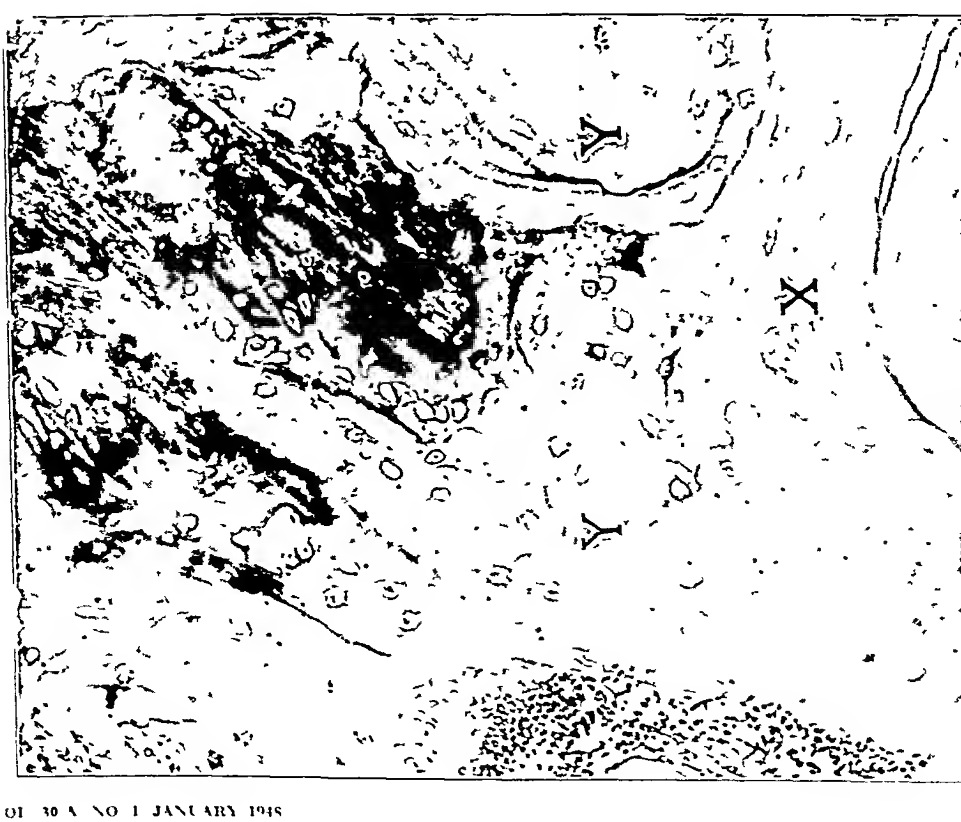

Fig. 3-D

Wall of cyst-like area in lunate. Necrotic bone, *X*, undergoing creeping substitution by living bone, *Y*.

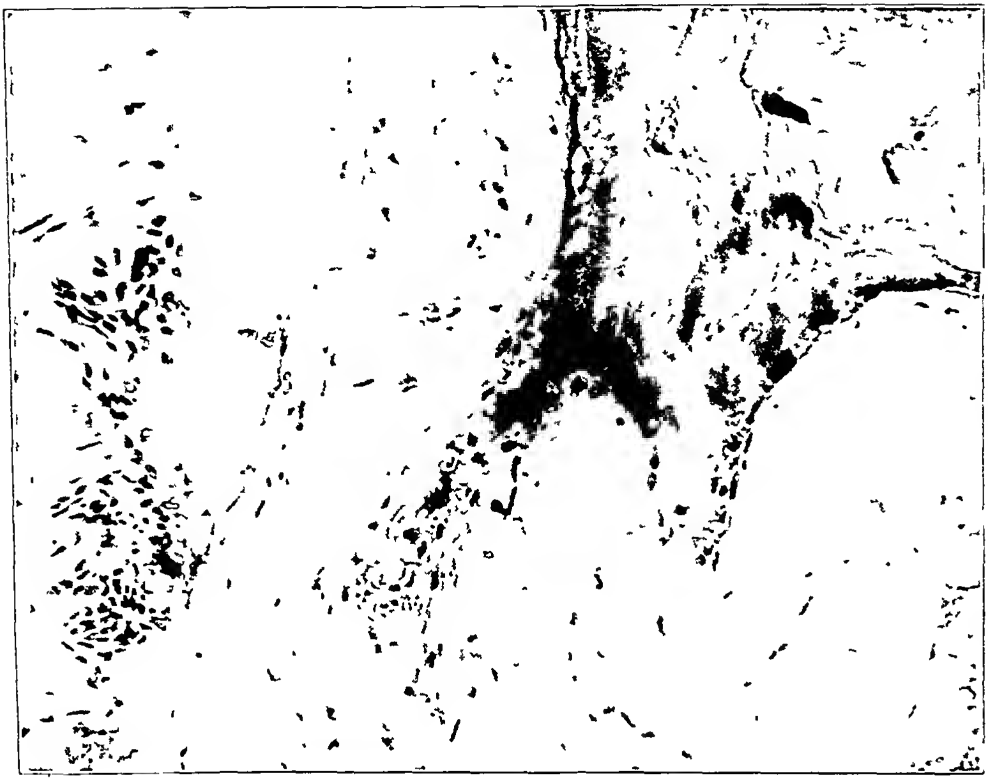

Fig. 3-E

Dense, partially calcified, fibrous tissue excised from central area in lunate.

Pathologically, the cyst-like areas of rarefaction in the carpal bones resemble th cysts of the capital femoral epiphysis, and their pathogenesis may be assumed to be essen tially the same. They also bear some resemblance to subcortical cyst-like areas in th femoral head and in the acetabulum at the weight-bearing region in chronic degenerativ arthritis. The severity of symptoms in these cases is probably dependent upon the severity of the associated degenerative arthritis. Surgical treatment is beneficial, but cannot be expected to provide complete relief from symptoms.

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CARTILAGE AND CHONDROITIN SULPHATE

III. CHONDROITIN SULPHATE AND INFLAMMATORY LESIONS OF CARTILAGE *

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The current literature contains discussions of the gross morphology of some inflammatory lesions of cartilage, resulting in cartilage destruction. Knowledge is, however, very meager as to the minute details of the actual changes in cartilage during these conditions, and all contributing factors are not known. To judge from earlier investigations, which will be mentioned later, more exact data are needed as to the content of chondroitin sulphate. In the present communication some additional data are supplied, and an attempt is made to correlate general biochemical characteristics of inflammatory changes with the morphological details of cartilage destruction due to inflammation.

Whether or not exudative non-infectious *synovitis* induces any changes in articular cartilage seems to be unknown, and will not be taken into consideration in this paper.

The changes in acute *infectious arthritis* vary according to the type of agent[3]. For example, rapid and complete cartilage destruction is seen in gonorrheal arthritis, while mild destruction or almost none at all is encountered in other types of arthritis. In the first classical description, Virchow stressed the breaking up of the intercellular matrix.

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This process was studied in more detail by Axhausen and Hellner[7], who described the destruction of cartilage by leukocytic action. The content of chondroitin sulphate did not attract any attention, but it seems fair to suppose that the early disappearance of chondroitin sulphate is a distinctive feature of infectious cartilage destruction[8].

In chronic *rheumatic arthritis*, focal cartilage degeneration (hyaline or fibrinoid) has been reported by Klinge, probably preceded or accompanied by a disappearance of chondroitin sulphate. Definite statements are lacking, but the suggestion mentioned gains some support by Hirsch. When considering this disease, we should bear in mind the multitude of factors involved, which include synovitis, altered composition of the synovial fluid, impairment of function, and formation of adhesions.

Regarding *tuberculous arthritis*, Heile, using polychrome methylene blue, reported the early disappearance of the typical metachromatic staining reaction of the intercellular matrix, whereby the collagenous fibrils were unmasked. Similar findings were published by Seggel, who also observed incidental remains of metachromatic material in areas surrounding degenerating chondrocytes. In a general way, the tuberculous cartilage destruction has been ascribed to the action of granulation tissue (leukocytes and lymphocytes) and of ingrowing connective tissue ("pannus")[6].

Various inflammatory lesions of other types of cartilage have been studied, but no attention has been paid to the content of chondroitin sulphate. The end result of such infections is usually cartilage necrosis.

The general conception is that cartilage presents a remarkable "resistance" to infection, which is perhaps partly attributable to its avascularity. Obviously, an exception must be made for the inflammations due to certain bacteria, such as *Neisseria gonorrhoeae*.

There are many possible factors responsible for the cartilage destruction due to inflammation; some of the most important will be mentioned. Thus, in the course of inflammatory lesions, changes occur in the hydrogen-ion concentration[11,12] and in the flow of blood and tissue fluid; and groups of different enzymes are interacting. Furthermore, cartilage cells are opposed to granulation tissue, containing fibroblasts and wandering cell elements. In a general way, we are justified in stating that the inflammatory processes create a new and different medium, containing biochemical factors liable to alter the normal conditions of cartilage physiology and nutrition. The deleterious effect of growing fibroblasts, as seen in tissue culture, might also be recalled[13].

MATERIAL AND RESULTS

For lack of sufficient material, only a small number of cases have been investigated. With the use of a correct metachromatic staining technique, according to Lison[10,15], the content of chondroitin sulphate has been estimated, and its distribution has been ascertained. Some technical data and the main results are summarized in Table I.

To judge from the material taken from patients with tuberculous arthritis and osteochondritis (Table I), it seems evident that cartilage alterations are gradual and may be divided into two phases. The first phase of inflammatory derangement of cartilage is characterized by a demonstrable decrease in the content of chondroitin sulphate of the intercellular matrix, which in other respects seems quite normal. This condition is found in cartilage areas adjacent to actual inflammatory foci, but not yet subjected to the inflammatory changes. Thus, in this stage no appreciable oedema or inflammatory cells are seen. The second phase involves the actual inflammatory changes with cell infiltration, granulation tissue, ingrowth by fibroblasts, and subsequent necrosis and digestion of cartilage. In this stage of alterations, usually no chondroitin sulphate can be demonstrated in the markedly changed intercellular medium. Yet, cartilage on the verge of necrosis may show thin pericellular halos of metachromatic stainability, indicating remains of chondroitin sulphate.

According to the observations of Hirsch, the focal lesions of joint cartilage in rheu-

TABLE I

THE ESTIMATED CONTENT OF CHONDROITIN SULPHATE IN CARTILAGE SUBJECTED TO INFLAMMATORY CHANGES

Material *	No. of Cases	Estimated Content of Chondroitin Sulphate
Tubereulous arthritie tissue (knee and hip)	7	*Normal cartilage:* Large eontent of chondroitin sulphate. *Inflammatory foci:* 1. In the surrounding, slightly oedematous, eartilage areas, without actual signs of inflammation, a gradual decrease in chondroitin-sulphate content was observed toward the inflammatory foeus. 2. In the periphery of the lesions, slight and beginning inflammation was present, characterized by exudation and leukoeyticinfiltration; a small amount of ehondroitin sulphate was observed. In places, ehondrocytes with periecllular halos of metachromatic material were seen. 3. In the center of the focus, with marked inflammatory signs and eartilage destruetion, the metaehromatic material was lacking. 4. Necrotie eartilage was devoid of the metachromatic staining reaetion.
Tubereulous osteochondritie tissue (ribs)	3	Same findings as above
Tissue of ehronie periehondritis (ear cartilage)	2	Selerosis and slight lymphoeytie infiltration of the perichondrial connective tissue. No inflammatory changes in the eartilaginous tissue itself. In its superfieial zone, the ear eartilage lacks ehondroitin sulphate. Somewhat deeper, toward the eenter of the eartilage, an inereasing eontent is seen.

* Fresh material, obtained at operation, was used, fixed in 8 per cent. formaldehyde solution. Sections, measuring 5 micra, were stained in 0.1 per eent. toluidine-blue solutions in alcohol at eoncentrations of 1 per eent., 30 per eent., and 50 per eent.

matic disease and infectious arthritis are also accompanied by a corresponding local decrease in the chondroitin-sulphate content, as stated.

The effects of chronic perichondritis were studied in ear cartilage (Table I). Fibrosis and lymphocytic infiltration of the perichondrium evidently induce a moderate decrease in the content of chondroitin sulphate in the superficial part of the underlying cartilage. It may also be mentioned that small superficial erosions of ear cartilage, filled by growing perichondrial fibroblasts, were found to evoke a similar decrease in ester-sulphate content of the neighboring cartilage zone.

To sum up, it seems evident that the very first sign of inflammatory derangement of cartilage, hitherto described, is a moderate decrease in the content of chondroitin sulphate, preceding the actual inflammatory lesions. This early loss of ester sulphate must be induced by the inflammatory process under question. The remaining bulk of chondroitin sulphate is rapidly lost when the advancing inflammatory process becomes established.

It should be noted, however, that, in the course of inflammation, cartilage does not present any signs of "dedifferentiation" or of regenerative proliferation. No indications of repair by transformation of perichondrial or other fibroblasts were observed [4].

DISCUSSION

Considering the active factors responsible for inflammatory destruction of cartilage, all possible interpretations will be defective for lack of sufficient data. However, in some respects the available observations afford a basis for some simple deductions. From an academic point of view, two separate stages of cartilage changes were distinguished: (1) a

gradual loss of chondroitin sulphate, preceding the actual inflammatory changes; and (2) the actual destruction and digestion of cartilage substance. Some conditions favor the opinion that these processes are effected by different chemical factors.

In conformity with the opinions presented in the first paper of this series [15], we have to emphasize the fundamental importance of the acid reaction of the intercellular medium in normal cartilage. From the works by Menkin on the chemistry of inflammation, we know that the hydrogen-ion concentration of the infectious foci must be near pH 7, or slightly on the alkaline side. Recalling the sensitivity of the native chondroitin-sulphate molecule to slight alkaline reactions [2], we thus arrive at the following explanation as being most likely: It seems probable that the gradual loss of chondroitin sulphate, as stated, constitutes a manifestation of a *gradual alkaline depolymerization and disintegration* of the molecule under question, effected by a peripheral spread (diffusion) of alkaline material from the central focus of inflammation. Other cooperating factors must not be overlooked, such as the possible effects of proteolytic and other enzymes, produced by growing fibroblasts, bacteria, or inflammatory cell elements; and further, a diminished production of chondroitin sulphate, either alone or in combination with an increased absorption. Among the enzymes, the possible role of hyaluronidase has been mentioned [15].

In the author's opinion, the inflammatory shift in pH toward the alkaline side, as discussed by Menkin, may be the chief operating factor responsible for the decomposition, or disappearance, of chondroitin sulphate. This factor has been omitted in previous discussions concerning morphological changes in cartilage.

Considering the second phase, characterized by digestion of the cartilaginous matrix and cell bodies, the action of proteolytic enzymes must be postulated. Such enzymes may be delivered by the different cell types of the granulation tissue. The cultivation experiments of Roulet also call attention to the biological effect of growing fibroblasts on cartilage.

As regards the sequelae of inflammatory derangement of the perichondrial connective tissue, it seems quite clear from the present results that such changes are capable of inducing a depletion of chondroitin sulphate in the underlying cartilage area. Recalling the function of the perichondrium [15], we may suggest that this loss of ester sulphate could be a manifestation of impairment of nutrition in the corresponding cartilage. However, this question cannot be decided for lack of additional data. Once more, the observation of small superficial erosions, evoked by ingrowing fibroblasts (Table I), requires attention as to the behavior of fibroblasts against cartilage [13].

From a physiopathological viewpoint, the present results seem to require further attention. Considering the strongly acid reaction of the normal intercellular cartilage matrix [15], and recalling that a neutral or slightly alkaline reaction is a prerequisite for the propagation of inflammation [11, 12], we are justified in suggesting that chondroitin-sulphuric acid, by its acid reaction, affords a protective action against the spread of inflammatory lesions. Judging from the present results, I venture the statement that the disintegration of chondroitin sulphate is a prerequisite for the propagation of inflammation in cartilage. The possibility of an alkali-binding function of chondroitin-sulphuric acid (or of its degradation products) must also be considered. Thus, these deductions lend some interpretation to the well-known "resistance" of cartilage to inflammation.

In the first paper of this series, the deficiencies of the present purely morphological conceptions of cartilage were considered. Before further progress can be made, we evidently must gain new and more correct insight into the normal physiology of cartilage. In the author's opinion, a correct basis for future research will be obtained by applying the present knowledge of the chemical and physical characteristics of chondroitin-sulphuric acid. This acid substance seems to afford a key to most of our current problems concerning cartilage physiology and physiopathology. This opinion is supported by the present studies on the physiological ossification and the inflammatory changes of cartilage.

SUMMARY

By means of a correct metachromatic staining technique, the distribution of chondroitin sulphate in cartilage during inflammatory conditions has been described. The results support the following conclusions:

Preceding the actual inflammatory changes, a decrease in the content of chondroitin sulphate was ascertained. Most of the ester sulphate is lost when the inflammatory changes become established. The observed depletion of chondroitin sulphate is probably effected by an alkaline depolymerization and disintegration of the molecule in question. Among different contributing factors, the alkaline hydrogen-ion concentration in inflammation seems to be of prime importance for the interpretation of the observations. The disintegration of the ester sulphate seems to be a prerequisite for the propagation of the inflammatory process in cartilage, and this in part explains the "resistance" of cartilage.

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PLASTIC REPAIR OF THE EXTREMITIES BY NON-TUBULATED PEDICLE SKIN FLAPS

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In wounds and burns of the extremities, a variable amount of tissue damage is produced. Experience has shown that wounds should be closed, and a skin covering should be obtained as soon as it is feasible, in order to eliminate infection and to minimize the formation of scar tissue. Gaping of wounds is caused by the eccentric pull of the surrounding elastic tissue and by the release of the continuous tension of the deep fascia. When the loss of skin and subcutaneous tissue is more apparent than real, closure by primary suture or by late primary suture may be possible. However, when there is loss of skin, the raw area must be covered by a free skin graft or by a pedicle skin flap. This principle is generally understood and applied. Over many wounds the free skin graft provides not only the immediate "skin dressing", but also an enduring surface repair. Under certain circumstances, however, free skin grafts are unsatisfactory, and the covering of the wound by a pedicle skin flap is required. The study of the indications, the applications, and the technique of using non-tubulated pedicle flaps constitutes the object of this paper. Observations have been made in a series of 781 pedicle-flap operations, performed by the author during the past six years, for the resurfacing of defects, resulting from traumatic injuries of the extremities.

SKIN GRAFTS AND SKIN FLAPS: THEIR RESPECTIVE INDICATIONS

The technique of skin-grafting is relatively simple, but skin grafts often fail to "take" satisfactorily when placed over poorly vascularized areas, and give poor protection to certain underlying structures, as they are comprised only of the epithelium and a portion of the dermis. Skin-grafting is a method of *immediate* transplantation of skin.

Pedicle flaps differ from skin grafts in their anatomical structure, since they are formed, not only of epidermis and dermis, but also of subcutaneous fat. They constitute a method of *intermediate* [1] skin transplantation, because at first the pedicle provides nutrition to the flap through its arteries, veins, and lymphatics. After a few days, the flap acquires vascular connections with the underlying bed. Later, after the softening of the peripheral scar, it receives vessels from the surrounding tissue. Thus a flap may survive, even over a surface presenting poor vascularization. The layer of adipose tissue in the flap provides elasticity and extensibility, permitting a certain degree of stretching over the surfaces of joints. It is also shock-absorbing, and resists the stress of weight-bearing, of shoe-wearing, and of commonplace trauma. Subjacent tendons may glide through this fat layer of the flap, which prevents the recurrence of scar tissue after the latter has been entirely resected. Therefore, when skin grafts are unsatisfactory, skin flaps are indicated.

Free skin grafts are unsuitable in five sets of circumstances:

1. *For Covering Densely Scarred Areas*

The complete "take" of a skin graft cannot be assured, when it is applied over a poorly vascularized surface, containing scar tissue which it has not been possible to resect entirely, either because the scar merges onto a joint capsule or bare bone, or because it incorporates large vessels or nerves. In such cases, even after an immediate "take", the free skin graft may break down secondarily. This complication is seen particularly when the free graft covers an area of functional stress,—such as a joint like the elbow or the knee, or a weight-bearing area of the foot.

2. *For Covering Bone*

Free skin grafts will take well over healthy periosteum and will resist ordinary trauma, if they are not placed in positions of functional stress. A free skin graft does not constitute a covering which will permit a secondary operation,—such as bone-grafting or a joint resection. A free skin graft receives little blood supply from the surrounding tissue so that it cannot be raised from its bed without danger of necrosis. Bare bone, if it is to survive, must be covered by well-vascularized integument. It should be covered at the earliest moment by a pedicle skin flap to prevent ischaemic necrosis, elimination of bone, possible infection, osteomyelitis, and sequestration.

3. *For Covering Tendons*

Tendons must be placed among tissues which permit gliding,—tendon sheath, paratenon, loose cellular tissue, or fat. In repairing tendons or freeing tendons which are bound in an overlying cutaneous scar, the importance of removing all of the surrounding scar tissue and of covering the tendons with the adipose tissue of a pedicle flap cannot be overstressed. These constitute the condition *sine qua non* for the success of tendon plastic surgery. Tendons, even when they have been carved out of a solid block of surrounding scar tissue, may glide, if they are surrounded by fat or loose cellular tissue.

4. *In Peripheral-Nerve Surgery*

A missile may cause injury not only to the bones, tendons, muscles, or skin and subcutaneous tissue, but also to adjacent peripheral nerves. It has become increasingly apparent that, in such cases, the covering of the nerve by normal, well-vascularized skin and subcutaneous tissue is an essential part of the peripheral-nerve repair for the following reasons:

a: A nerve constricted by scar tissue loses its conductivity. If the nerve is anatomically intact, freeing it from the constricting extrinsic scar will usually hasten its recovery and will seldom retard it. If the severed nerve must be sutured, it is essential that the return of conductivity be unhampered by the scar.

b: The covering scar tissue may provide inadequate protection to the nerve, when it is superficial. The injured nerve may become superficial in position, as a result of the destruction of overlying muscles. In healed wounds of the posteromedial aspect of the elbow, the ulnar nerve may lie immediately beneath the scar tissue or may even be incorporated in the scar itself.

c: Pain may be caused by the presence of scar tissue around a nerve. Sensory fibers from the nerve may become incorporated in the overlying scar, thus constituting a painful scar. Such "intracutaneous neuromata" can be cured only by total excision, and replacement of the scar containing the constricted sensory-nerve endings. A flexor tendon may become adherent to the median nerve, causing pain by pulling on the nerve in the course of its excursion, until the nerve is freed from the binding scar. Many incomplete nerve injuries are associated with causalgia-like pains, which may be relieved by the dissection of the extrinsic scar and by placing the nerve in a new bed, where it is surrounded by normal tissue. Pedicle flaps of skin, transplanted over the nerve, give the latter a well-vascularized protective covering, which a free skin graft fails to provide.

5. *When Secondary Operations Are Necessary in the Repaired Area*

An area in which an operation upon the bones, the tendons, the ligaments, or the joints must be performed, or through which it is desired to explore a peripheral nerve, must be covered by a skin flap, which alone will be sufficiently resistant to withstand the incisions, the undermining, and the unavoidable manipulations of the operation. The use of skin flaps also permits combined simultaneous operative procedures on tendons or nerves, the overlying defect being immediately covered by a pedicle flap of skin.

GUIDING PRINCIPLES IN PEDICLE SKIN FLAPS

After transplantation, the flap must live on its pedicle until, through a process of granulation, new vessels have grown into the under-surface of the flap from the recipient bed.

The width of the pedicle must be sufficient to ensure arterial supply and venous and lymphatic return. In an immediately transferred flap, unless the flap contains a large arterial and venous supply, its length should not exceed one and one-half times its width.

Incisions outlining the flap should be carried down to deep fascia, and the flap should be raised by separating the fat from the fascia. In this manner, injury to the main nutrient vessels traveling through the fat is avoided. The disparity of thickness of a transplanted flap and the surrounding tissue may be a temptation to thin down the fat layer at operation. Only experience can guide in the extent of the resection which may be thus practised, because of the danger of injuring the nutrient vessels. The line of attachment of the flap should cut across the general direction of the vessels, so as to receive the greatest possible blood supply. Skin flaps may be taken from the immediate vicinity of the defect, or from a distance from the defect. The former are called local (or contiguous) flaps.

LOCAL FLAPS

The possibility of shifting tissue by local flaps is explained by the natural elasticity of the skin, which permits its adaptation to new positions. At no time, however, should this elasticity be abused, so that the flap is made to assume its new position under tension. Whenever the defect to be covered is not too extensive, and when sufficient tissue is available in the vicinity of the defect, its repair by local flaps is to be preferred. The technique is simple and rapid in comparison to that of transferring a flap from a distance. Local flaps generally give a more suitable repair, because adjacent tissue is employed. When the surrounding tissue is very loose, particularly in older individuals, it is possible to undermine the skin edges around the defect by freeing the fat layer from the fascia. This undercutting permits the stretching of the skin in straight-advancement flaps. However, it must be stressed that the proper use of local flaps implies the mobilization of skin from an area adjacent to the defect, in such a manner that the secondary defect produced may be closed without causing tension upon the suture line of the primary defect. To achieve this, it is necessary to shift the flap through an angle approaching 90 degrees. When the secondary defect cannot be closed by direct approximation, the flap must be taken from an area upon which a free skin graft can be applied without causing any functional disturbance. Often an advantageous barter of tissue can be carried out,—for example, when a flap is raised to cover a tendon, and the secondary defect is repaired satisfactorily by a free skin graft (Figs. 1-A, 1-B, 1-C, and 1-D).

Local flaps fall into one of two main types,—transposed flaps and rotation flaps.

1. *Transposed flaps* are raised at an angle to the defect and are then applied over the latter (Figs. 1-A, 1-B, 1-C, and 1-D). Such a flap should be borrowed from an area where tissue is abundant, so that a direct closure of the secondary defect may be possible (Fig. 2). By a procedure of double transposition, popularly known as "Z flaps", shortness of skin, resulting in contractile bands of scar tissue, can be remedied. Bipedicle transposed flaps are less mobile than unipedicle flaps, and are more limited in their use. They find their best application when their transfer is effected by a change of plane (Fig. 3).

2. *Rotation flaps* permit the shifting of adjacent tissue along a curved line, on which the tension is evenly distributed. There are two varieties of rotation flaps,—the swinging-rotation flap (Fig. 4), and the advancement-rotation flap (Fig. 5). The latter flap has been little used by the author. The swinging-rotation flap is rendered mobile by a counterincision, *ab*, the "tail" of the rotation flap (Figs. 4,*A* and 4,*B*). After the flap has been shifted, a secondary defect is produced, which is closed by direct approximation. Large secondary defects may require skin-grafting. The line of suture of the secondary defect tends to form

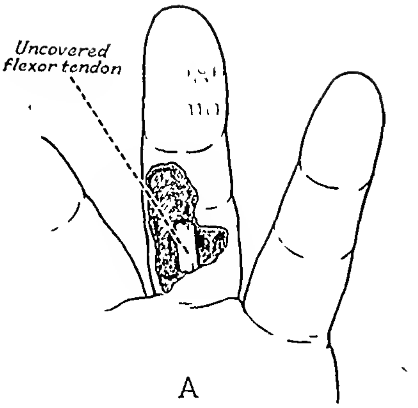


Fig. 1-A

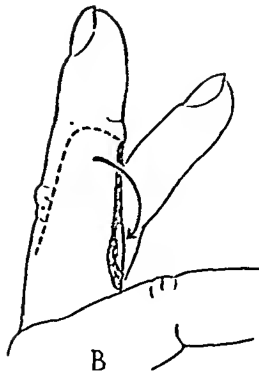


Fig. 1-B

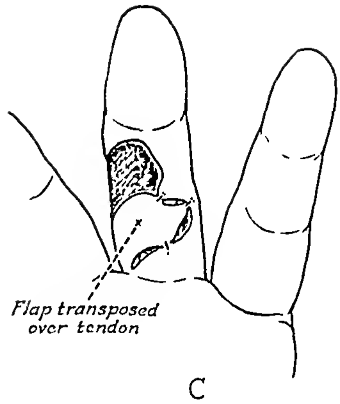


Fig. 1-C

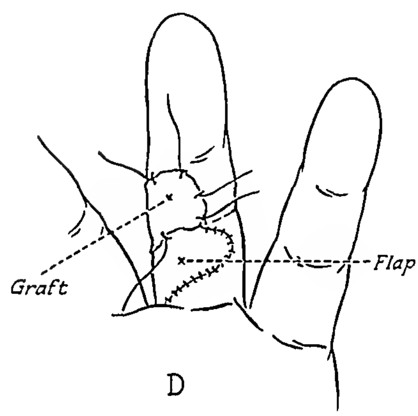


Fig. 1-D

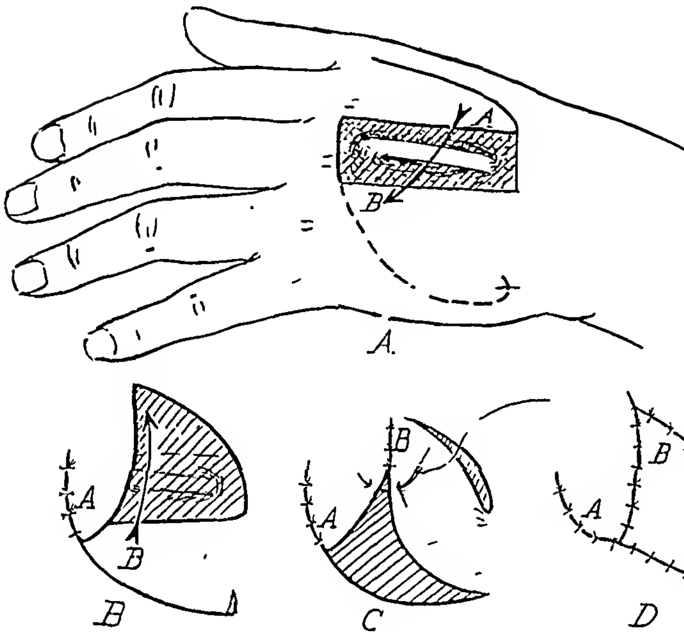


Fig. 2

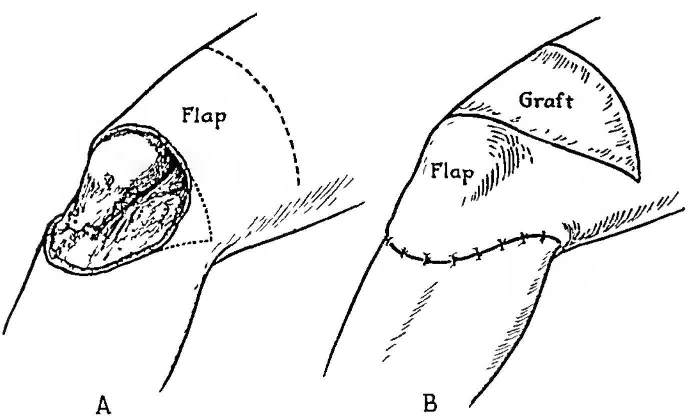


Fig. 3

Figs. 1-A, 1-B, 1-C, and 1-D: Transposed flap. Example of useful application of a flap, transposed from the lateral aspect of the finger, to cover an exposed flexor tendon. The raw area, resulting from the transfer of the flap, is covered by a free skin graft of intermediate thickness.

Fig. 2: Transposed flaps. Two flaps, *A* and *B*, are transposed over a defect which left an extensor tendon uncovered. Direct closure is possible, after wide undermining of the surrounding skin, because the skin of the area is abundant and loose.

Fig. 3: Bipedicle transposed flap. A good application of a bipedicle transposed flap to cover a patella denuded of periosteum. In *B*, the donor area has been skin-grafted.

a 90-degree angle with the line of tension of the flap. In this manner added tension on the latter is avoided. The combined use of transposed and rotation flaps has permitted a wide scope of applications in the repair of defects of moderate size.

Limitations of Local Flaps

The utilization of local flaps is limited by the size of the defect and by the type of tissue which surrounds the defect. Local flaps of large size necessitate the shifting of tissue situated around the circumference of the extremity and thus produce a circular scar.

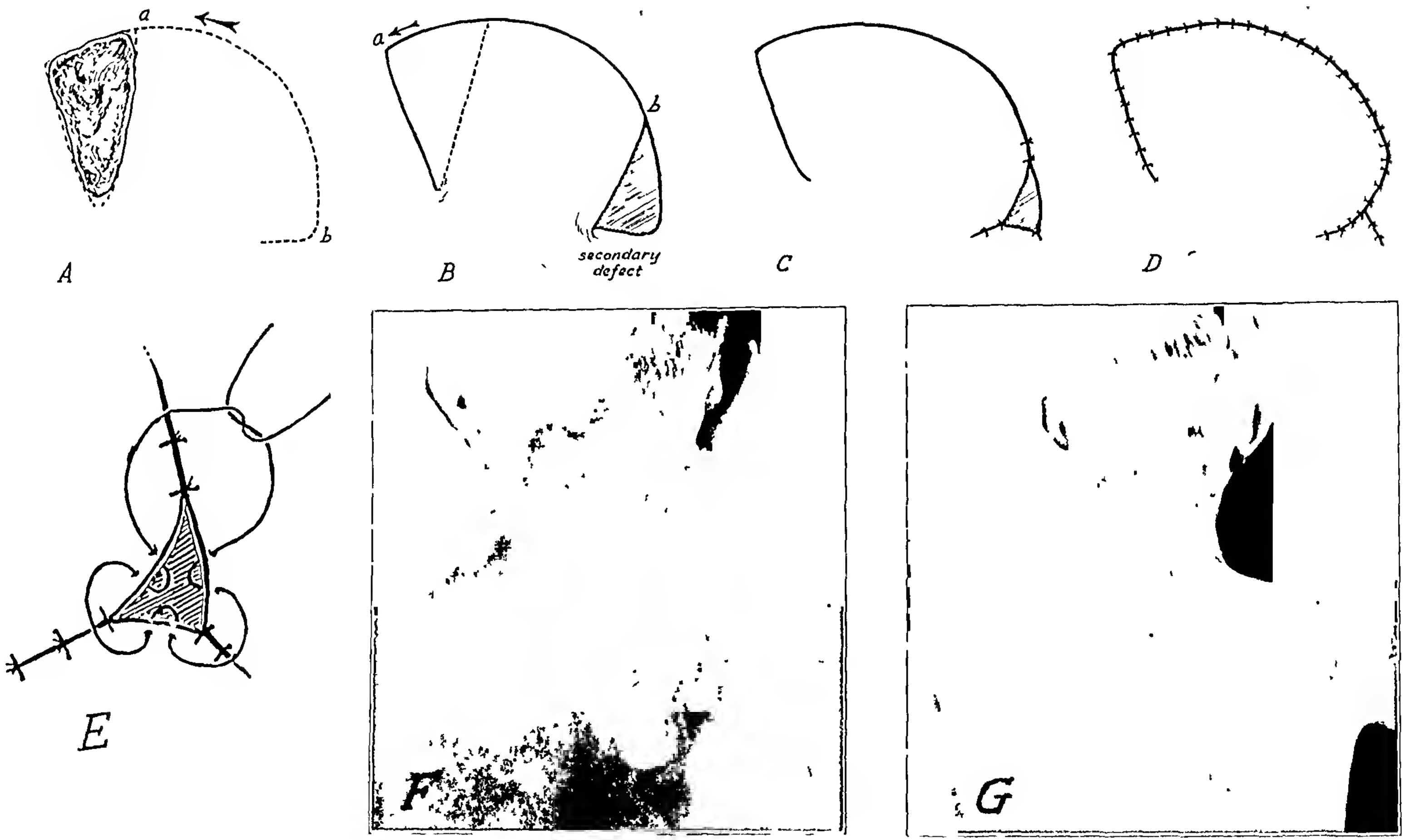


Fig. 4

Swinging-rotation flap. A, B, C, D, and E are diagrammatic representations of a swinging-rotation flap. The "tail" of the rotation flap, b, facilitates the movement of the flap. The secondary defect is closed at a right angle with the line of tension of the flap (C, D, and E). F and G show application of a swinging-rotation flap to cover a suprascapular defect.

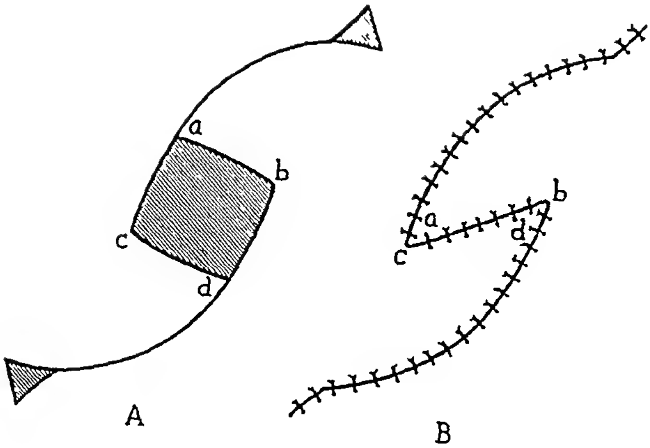


Fig. 5

Advancement-rotation flap. The excision of the triangles at the base of the rotation flaps facilitates their advancement and rotation.

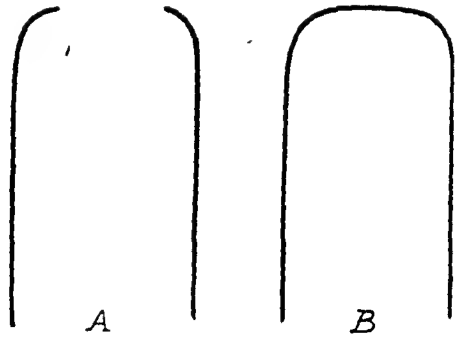


Fig. 6

Delayed flap. In a first stage, *A*, the flap is raised from the underlying fascia between two lateral incisions outlining the angles of the flap. In a second stage, *B*, the whole flap is raised and transplanted.

obstructing the lymphatic and venous return, at least temporarily. When the skin situate around the defect is loosely bound to the underlying fascia, it is possible to transpose o to rotate adjacent flaps in an efficient manner. This procedure is often possible in th upper extremity. In the hand, local flaps are satisfactory on the dorsum, but often fail i the palm, where the skin is thickened by a heavy layer of corneum and rendered tight an resistant by fibrous septa, which bind it to the deep palmar fascia. In the lower leg, th ankle, or the foot, local flaps must be executed with greater prudence, often after a pre liminary delay, because the skin is less elastic than in the upper extremity. When place under any degree of tension, such flaps tend to become necrosed by diminution of th blood supply. This danger is the greatest when dealing with the skin of the sole of th foot, which is functionally differentiated skin. In such areas, experience has proved tha flaps from a distance are indicated in all but small defects.

FLAPS FROM A DISTANCE

Flaps from a distance may be defined as distinct from local flaps by the fact that they are carried over an area of normal skin, before reaching the defect. Distant flaps may be taken from a donor site, situated not far from the recipient area; they may be carried from the donor site to the recipient area on the forearm, wrist, or hand; or they may be migrated by reimplanting one detached end of the flap into a position closer to the defect.

Types of Flaps from a Distance

Flaps from a distance may be called *direct* when the flap, after being raised, is transferred immediately to the recipient site, and *indirect,* when it is carried or migrated to the recipient area. Such flaps are *open,* presenting a raw area on the undersurface, or *closed* when this raw area is eliminated by one of three methods:

1. By tubing the flap (Gillies);
2. By skin-grafting the undersurface of the flap;
3. By covering this undersurface with another skin flap.

Open direct flaps may be transplanted *undelayed,* when, after being raised, they are sutured at once into the defect. However, the vitality of such flaps may be doubtful:

1. When the length of the flap exceeds one and one-half times its width;
2. When the flap must be twisted or kinked to reach its destination;
3. When the flap must be cut counterwise to the direction of the blood supply, or when it must cross the mid-line. Across the mid-line of the trunk, the blood vessels present fewer and smaller anastomoses than they have on each side of the mid-line.

TABLE I

COMPARATIVE APPROXIMATE LENGTH OF TIME REQUIRED BY DIFFERENT METHODS OF SKIN REPLACEMENT

Type of Flap	Days Required
Local flap	10
Free skin graft	10
Direct pedicle flap	24
Direct open "delayed" flap	38
Closed carried flap	32 to 52
Abdominal tubed pedicle flap, carried on the wrist	53 to 73

Under these conditions, if the viability of the flap is questionable, it should be *delayed* by a preliminary section of the vascular connections of the flap on the sides of the flap and beneath it. This procedure causes an increase in the size and number of the longitudinal vessels in the flap [4]. In performing a delayed flap, it is preferable to avoid raising the whole flap; instead, two longitudinal incisions, curved to outline the corners of the flap, are made, and the flap is raised from the fascia between these two incisions (Fig. 6). In this manner, there is no postponement of the transfer because of an ischaemic necrosis of the end of the flap. The transfer of a flap, after delay, can usually be accomplished in ten to fourteen days. There does not appear to be a contra-indication to postponing the transfer of the flap for a number of weeks after the delay, as the lateral blood vessels do not grow through the scar until after the latter has become softened. It is felt that, if the flap is cut and completely raised, as is frequently practised, and if necrosis does not ensue, this preliminary delay of the flap is an unnecessary and superfluous procedure. It will be objected that the angle of transfer of the flap may be such that it will not survive unless a delayed flap is used. If such an angle is necessary, it is probable that the flap was badly planned. It is interesting to note that in the author's series of 379 flaps from a distance, only eight were delayed flaps.

A widely known delayed flap is Gillies's tubed pedicle flap. The advantage of the tubed flap is the relatively long time required for its construction and transfer (Table I). The tubed pedicle flap will remain the method of choice for the transfer of abdominal flaps by migration to the lower extremity in aged patients, to whom a direct cross-leg flap causes too great a discomfort. When, for aesthetic reasons, a cross-leg flap is contra-indicated in female patients, the tubed pedicle may be transferred by way of the wrist.

Because of their greater speed of execution, direct flaps have been employed whenever possible in the present series of patients, who were nearly all war casualties and young, healthy, male patients. Before any flap is planned, it is essential to obtain the exact measurements of the defect to be repaired.

The Apparent Defect and the True Defect

The true defect is not represented by the size of a cutaneous scar, because contraction of the wound occurs in the course of wound healing. Furthermore, the area of the subcutaneous scar always exceeds that of the cutaneous scar, because the skin has been drawn over the wound during the process of healing. In consequence, a scarred surface should be excised widely, so as to remove all of the subcutaneous scar tissue. Scar contraction is greater when the skin of the area is loosely bound down to the underlying structures. It is marked in the vicinity of joints, because the latter have become flexed or extended, thus diminishing the size of the healing wound. The healed area thus constitutes only the apparent defect, which is smaller than the true defect. The size of the latter may be determined by a procedure which we may call "mapping".

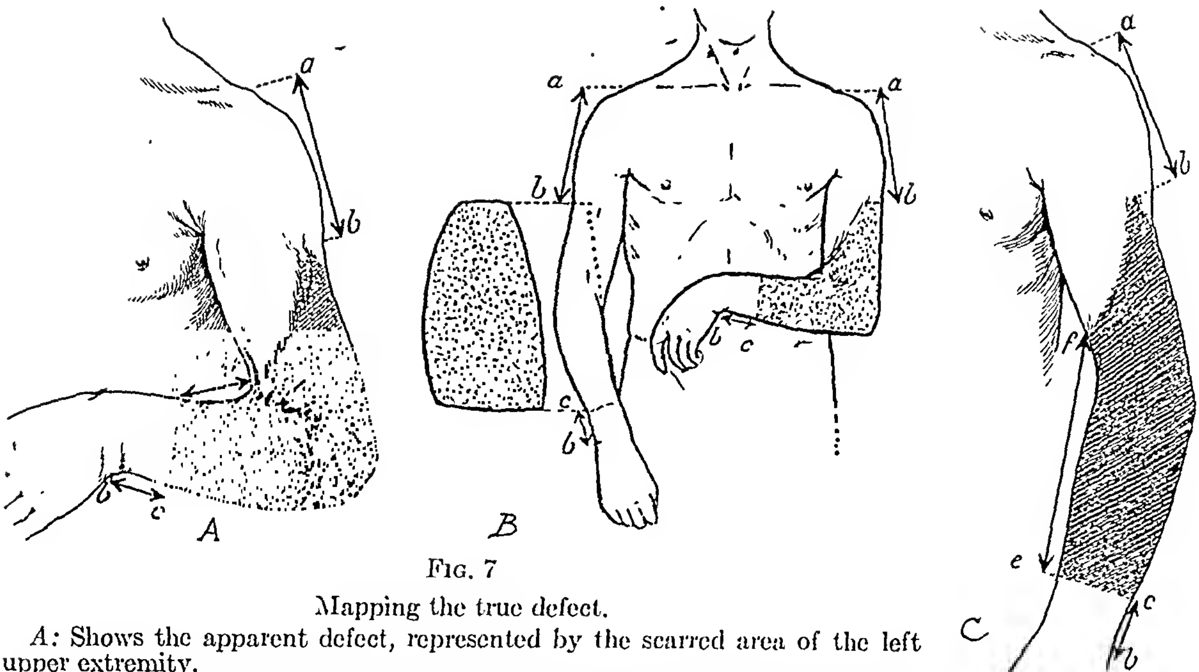


Fig. 7

Mapping the true defect.

A: Shows the apparent defect, represented by the scarred area of the left upper extremity.

B: The distances *ab* and *bc*, measured on the left upper extremity, are transferred to the unaffected right upper extremity. The true homologous defect can be mapped out on the right upper extremity.

C: The true defect becomes apparent after the excision of all scar tissue. Compare the size of the shaded area in *A* to that in *C*.

Mapping the Defect

Accurate mapping of the true defect can be done when the opposite limb is unaffected (Fig. 7). The procedure of mapping the defect of a scar contracture of the arm and forearm would be carried out as follows:

The upper extremities are compared; on the affected limb, bony landmarks (such as the acromion and the radial styloid) are marked on the skin with ink (Fig. 7,*B*). The distance *ab* from the superior limit of the scarred area to the acromion is noted, and an equivalent distance, *ab*, from the acromion is marked on the normal arm.

After the distance from the lower border of the defect to the radial styloid, *bc*, has been noted, the distance *bc* is measured on the normal arm (Fig. 7,*B*); the upper and lower limits of the true defect are thus obtained. The distance between the medial and lateral limits of the scarred area is obtained by passing the measuring tape around the unscarred portion of the arm at the point where the scar appears the widest; this measurement is noted on the normal arm, and thus is obtained the width of the true defect. By repeating these manoeuvres, each corresponding point of the true defect can be obtained; these points are then joined by a line, limiting the true defect which will be obtained after the complete excision of the scarred skin and underlying scar tissue (Fig. 7,*C*). After the extent of the defect has been determined by mapping, the flap should be carefully planned and designed before the operation is attempted.

The Planning of the Flap

In planning a skin flap, the following points should be observed:

1. *The flap operation should cause as little discomfort as possible to the patient.*

This condition is particularly important in older patients. It is also an insurance in favor of adequate immobilization during the healing of the flap, as a patient who is uncomfortable will become restless and endeavor to modify his position. In the repair of defects of the finger tips, flaps from the thenar eminence to the finger tips, from one finger to its neighbor (cross-finger flaps), from the opposite arm to the finger, and from the opposite forearm to the finger cause little discomfort.

In the repair of defects of the hand, flaps from the opposite forearm and arm have been used often in preference to thicker abdominal flaps for the repair of the palm. The use of a flap taken from the opposite upper extremity, chosen for reasons described later, necessitates the immobilization of both upper extremities in the cross-arm position. Such positions are inconvenient, not only on account of the discomfort, but also because of the temporary loss of function of the arms.

The forearm and arm can be covered generally by abdominal or chest flaps. The position of the upper extremity against the trunk which is the least uncomfortable for abdominal and chest-flap transfers is the following: The hand is placed over the opposite upper quadrant of the abdomen; the forearm, elbow region, and arm can then be held firmly immobilized against the trunk by means of a many-tailed abdominal binder. For the lower extremity, the easiest position of transfer is the cross-leg method, which is not unduly uncomfortable, provided that hyperflexion or hyperextension of the knee and external rotation at the hip joint are avoided and that firm immobilization in plaster is assured. The discomfort caused by a cross-leg flap is less than that caused by the transfer of a tubed pedicle flap carried on the wrist to the lower extremity.

2. *The transfer of the flap should be accomplished as quickly as possible.*

Rapid repair will accelerate the patient's return to normal activity and work, and the date of any secondary operation is advanced. Direct flaps are the most rapidly executed.

3. *The skin flap should be removed from a suitable donor area.*

The raising of a skin flap creates a secondary defect; therefore, the donor area of a flap should be chosen with care, particularly in female patients.

Whenever possible one should choose a region, such as the abdomen, in which a secondary defect may be closed by direct suture.

It is essential to select a region where a secondary defect may be repaired satisfactorily by skin-grafting. A flap should not be removed from over bone which is immediately subcutaneous, because the full thickness of the skin is needed to protect the bone.

The loss of tissue in the donor area should be less important than the repair of the primary defect. Thus an abdominal defect, created by the transfer of a flap to the hand, is of little importance if it has made possible the covering of denuded tendons.

The best match of tissue texture and thickness is achieved when the skin of a homologous region can be utilized,—for example, a cross-leg flap.

The Design of the Flap

After the extent of the true defect has been determined and the flap to be utilized has been planned, an accurate design of the future flap may be obtained by the method described by Gillies. The recipient and donor areas are brought into the positions they will assume during the transfer of the flap. A pattern is cut to shape, and fitted as though the operation of flap transfer had been finished (Fig. 8,*D*). The pattern is held to the donor area while the recipient limb is displaced and it is then spread over the donor area (Fig. 8,*E*). Its exact position is noted, and the patient's name is marked on the pattern, which is sterilized in readiness for the operation.

The following points should be observed in designing a flap:

1. The length of the flap should not exceed one and one-half times its width.

2. The angle at which the flap leaves the donor area should be as wide as possible, so as to avoid a kink detrimental to its blood supply.

3. Tension on the flap should be avoided, not only by employing a flap of adequate dimensions, but by the careful choice of the best angle for the line of attachment of the pedicle flap.

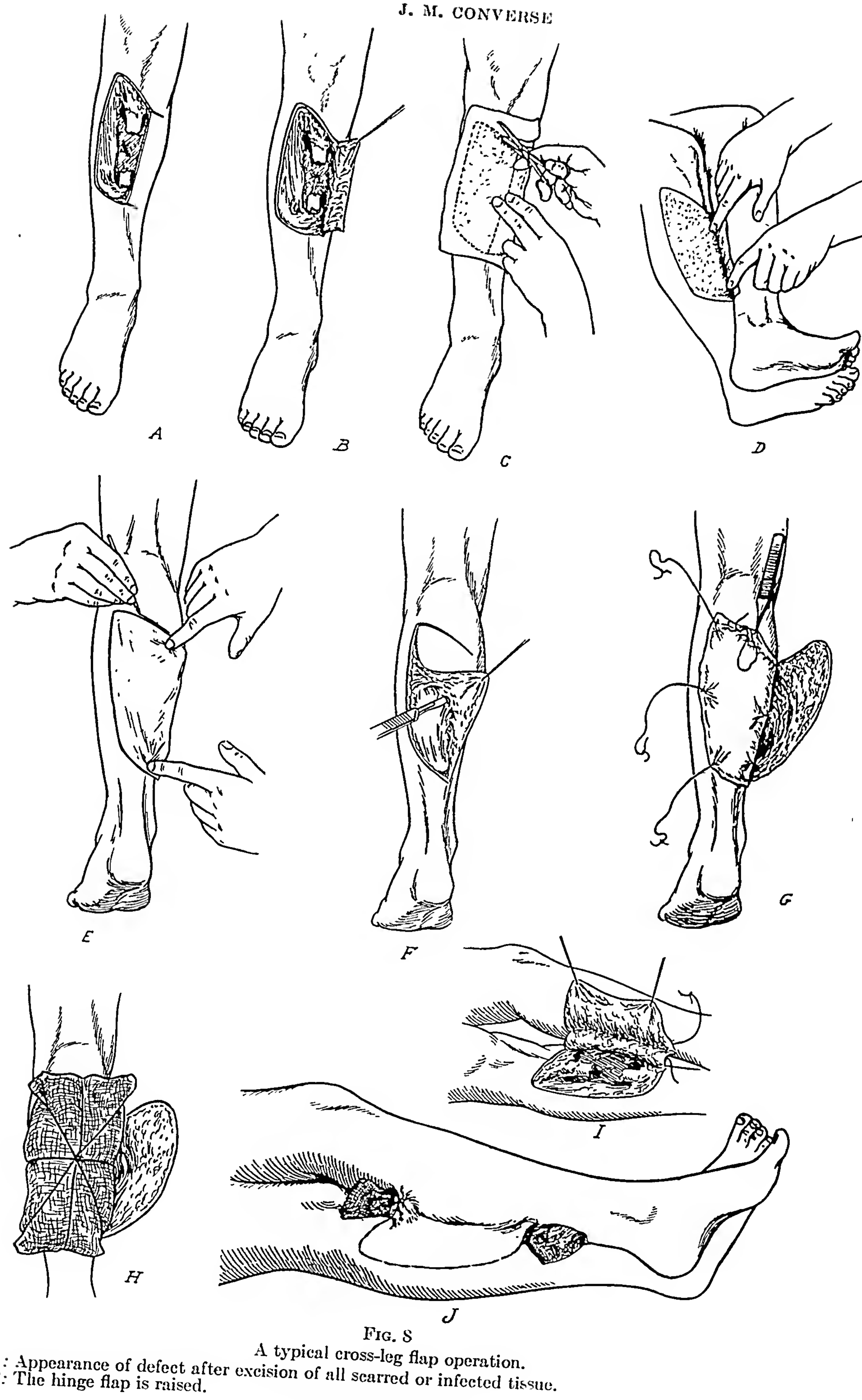


FIG. 8
A typical cross-leg flap operation.
A: Appearance of defect after excision of all scarred or infected tissue.
B: The hinge flap is raised.

(*Continued on page 173*)

FIG. 8 (*Continued*)

C: The pattern of the defect is made.
D: The pattern is placed as though the flap transfer had been completed.
E: The pattern is placed over the donor area and is outlined with ink.
F: The flap is raised from the deep fascia.
G: An intermediate-thickness skin graft is sutured over the defect produced by raising the flap.
H: Tied-in pressure dressing over the skin graft.
I: The hinge flap is sutured to the base of the cross-leg flap.
J: The cross-leg flap in place. Intradermal sutures avoid the need for skin sutures.

FIG. 9-A

FIG. 9-B

Pedicle-flap covering of the saucerized bone cavity.

Fig. 9-A: Shows saucerized granulating cavity of the distal portion of the tibia.

Fig. 9-B: The cavity has been lined with a thin skin graft, applied on a mold of dental compound. (This skin graft over bone is unstable and the author feels that this stage is unnecessary.)

Fig. 9-C: The cavity has been covered by a cross-leg pedicle skin flap after the removal of the skin graft.

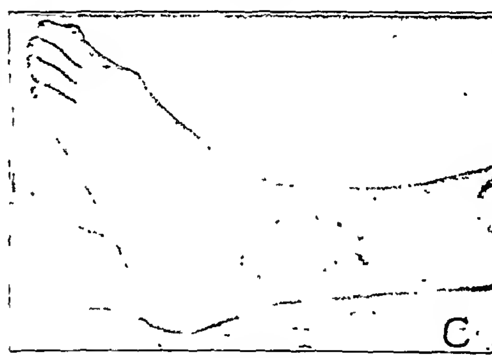


FIG. 9-C

Preparation of Wound for Flap Transfer

Often a flap is applied to replace an unstable scar, covering bone or incorporating within its mass, tendons, nerves, or joints. In an increasing number of patients, the early application of a flap to an open wound with loss of tissue is followed by success, if suitable preparation of the wound is carried out.

In the early part of the War, in the cases of this series, all wounds of compound fractures with loss of soft tissue were treated by the closed plaster method until consolidation of the fracture. The soft-tissue defect was repaired early by free skin-grafting, but necessary flap repairs were done later[2]. In many cases, consolidation did not occur; and in some, considerable necrosis and sequestration of the uncovered bone took place. All in all, the treatment of such cases was greatly prolonged. Some wounds and saucerized bone cavities were even skin-grafted so as to obtain complete healing before a flap was contemplated (Figs. 9-A, 9-B, and 9-C). Wounds with superficial-tissue loss presented added tissue loss by ischaemic necrosis of the exposed tissue and by infection and suppuration; prolonged exudation and suppuration caused nutritional disturbances due to protein loss.

The great advantage of obtaining a rapid covering of such wounds gradually led to the earlier use of flaps over open wounds. However, careful consideration should be given each wound before operation. Indications for postponing the flap operation are redness and oedema of the wound margins, elevation of temperature, and profuse discharge. The presence of a hemolytic streptococcus in the wound is considered as a contra-indication to

operation. Penicillin therapy is instituted, and moist dressings are applied, with pressure over the wound and with a pressure bandage over the portion of the extremity distal to the wound. The immobilized extremity is elevated.

Windows in the plaster were found to lead to wound oedema; instead, the plaster was bivalved to permit changes of dressings, if these were required. Closure of a wound by a flap should not be done when the wound is discharging pus, as this usually indicates the presence of infected and necrotic tissue in the depth of the wound. Such a wound can be closed by a flap only if complete excision of all devitalized tissue can be done, if the wound presents no recesses, and if the wound can be laid flat in such a manner that the flap can be applied without leaving any dead space under it.

In dealing with compound fractures discharging pus, immobilization in plaster is necessary. In compound fractures of the leg, one should be particularly careful to obtain control of the suppuration before covering the wound with a flap, as there is no adequate posterior drainage route for the shaft of the tibia. Before a plaster is applied, all necrotic tissue and loose bone fragments should be removed, recesses in the wound should be opened, and the wound should be packed open with gauze. When bone is devitalized through exposure, it should be removed surgically before the remaining bone is covered by a flap, in order to prevent burying dead bone under the flap.

All flap operations over open infected wounds were considered to justify a protective penicillin "cover" which was given postoperatively until the likelihood of invasive infection was passed.

TECHNIQUE OF THE TRANSFER OF FLAPS FROM A DISTANCE

Certain points of technique are common to all flap transfers; others are specific to certain particular flaps.

I. *Technique Common to All Flaps*

A. *Hemostasis*

A flap of the suitable size and shape having been cut, and the recipient area having been completely freed of all scar tissue, it is necessary to ensure that all bleeding vessels have been ligated, so as to avoid a hematoma under the flap. Silk, of the finest size, appears to be well tolerated beneath a skin graft. It is tied with the needle holder.

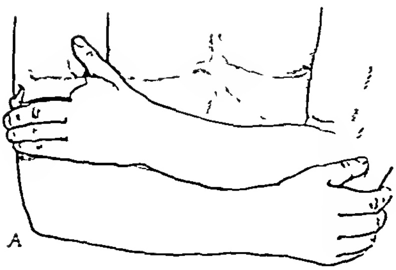
B. *Suture*

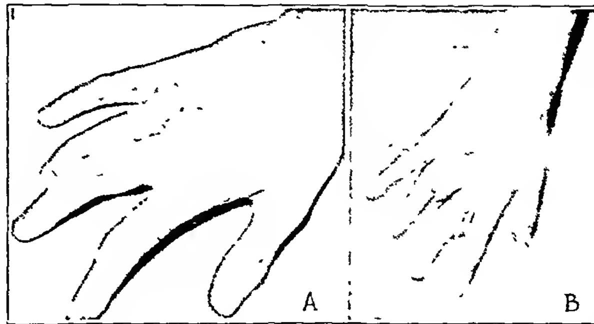
Careful suture of the edges of the flap to the edges of the surrounding skin is essential to achieve good primary healing. Usually the flap is thicker than the surrounding skin and subcutaneous tissue; and thinning of the flap by resecting some of its fat is hazardous, because it endangers the blood supply to the flap. However, accurate apposition can be obtained by placing numerous U-shaped intradermal sutures of white silk or cotton so that the skin edges are approximated, even without placing skin sutures. These intradermal sutures are of special value when immobilization in plaster is carried out, particularly for cross-leg flaps. They avoid stitch abscesses or even stitch marks, caused by skin sutures left under a plaster cast. Epithelial apposition may be completed by placing a few sutures of the finest material (size 6-0 silk). Such fine sutures, placed without undue tension, may be kept in place for two or three weeks without causing inflammation.

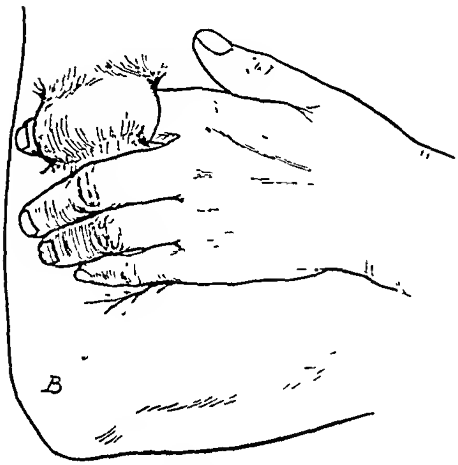
C. *Elimination of the Raw Area. Skin-Grafting the Donor Area*

One should endeavor to make the procedure of a flap transfer a closed operation by eliminating raw areas, produced by the raising of the flap, in the following manner:

1. By bringing the recipient area as close as possible to the donor area along the line of attachment of the flap.







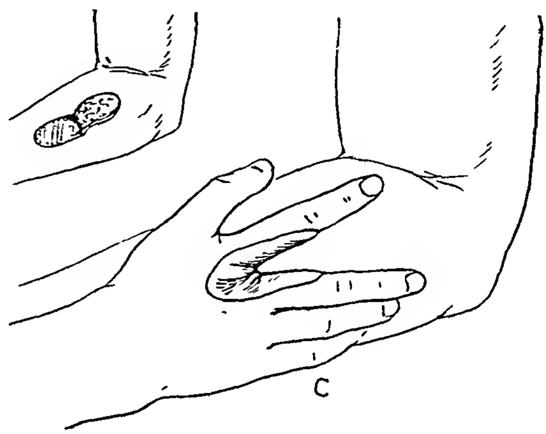


FIG. 10

FIG. 11

Fig. 10: Positions of transfer for cross-arm flaps.
A: Flap repair of finger.
B: Bipedicle flap repair of finger.

Fig. 11: *A:* Syndactylism with adhesions of extensor tendons in the scar and synostosis between the third and fourth metacarpal bones.
B: Appearance after the restoration of the interdigital space.
C: The cross-arm flap procedure was used in this case which required a skin flap, rather than a free skin graft.

Fig. 12: Cross-arm flap. A flap taken from the opposite forearm furnishes soft and pliable skin for the resurfacing of the palm of the hand.

FIG. 12

2. By skin-grafting immediately or closing by direct approximation the raw area, produced by the raising of the flap. A split-thickness skin graft, held to the edges of the defect by a continuous running lock stitch, and maintained by a pressure dressing tied into the defect, gives a satisfactory repair (Figs. 8,*G* and *H*). When moderate-sized flaps from the abdomen are employed, one can close the defect by carefully suturing the wound after extensive undermining. A continuous intradermal suture with a stainless-steel wire (gauge 35) closes the wound with an even distribution of tension. Since the suture is usually well tolerated, it may be left *in situ* from ten to fifteen days. It is preferable, however, to skin-graft the defect, rather than to attempt to close it with undue tension.

3. By employing the hinge flap.

As stated previously, the portion of the flap situated between the recipient area and the attachment of the flap should be as short as possible. However, in order to eliminate completely the raw area under the flap, it has been found advantageous to make a hinge

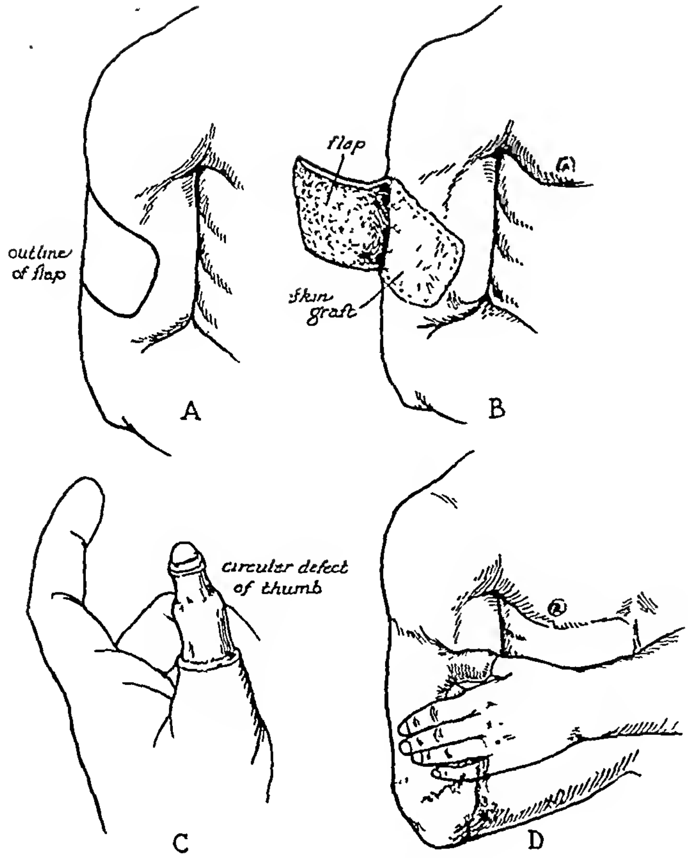


FIG. 13

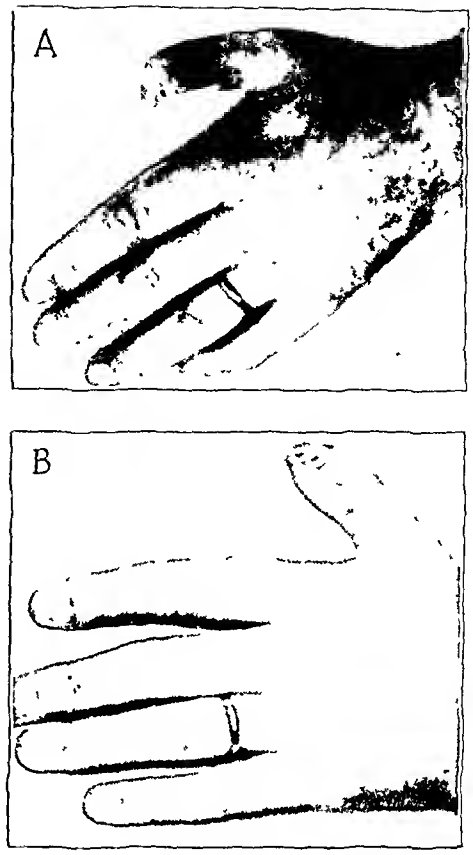


FIG. 14

Fig. 13: Covering of a circular defect of the thumb.
A: Outline of direct flap on anterior lateral aspect of the right arm.
B: The flap is raised; an immediate skin-graft covering is provided to the raw area left by the raising of the flap.
C: Appearance of circular defect of the left thumb after excision of the scar tissue.
D: The brachial flap has been applied to the thumb defect.

Fig. 14: *A:* Circular loss of skin of the left thumb, as a result of crushing.
B: Replacement of skin covering, as shown in Fig. 13.

with normal skin on the side of the defect opposite the attachment of the pedicle flap (Fig. 8,*B*). This hinge flap is sutured to the undersurface of the main flap, thus closing it completely along its base. The hinge flap has been shown to present the following four main advantages:

a: The avoidance of infection and suppuration on the undersurface of the flap, particularly when the defect presents exposed tendons, which are especially susceptible to infection.

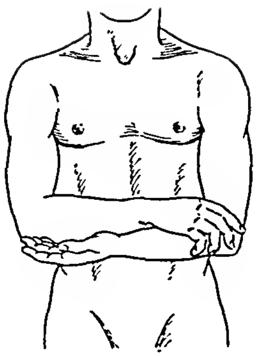
b: The avoidance of inflammation after the section of the pedicle along the line of secondary suture, because the area has been kept rigorously closed by the hinge flap.

c: The elimination of tension, and thus of inflammation and of delayed healing, along the line of suture of the sectioned pedicle. It was noted repeatedly that, when there was an excess of tissue, such as is provided by the hinge flap, thus eliminating tension, healing occurred satisfactorily. Slow healing due to tension along the line of section of the pedicle was seen particularly in flap repairs of the foot. The adoption of the hinge flap greatly accelerated the healing time of such wounds.

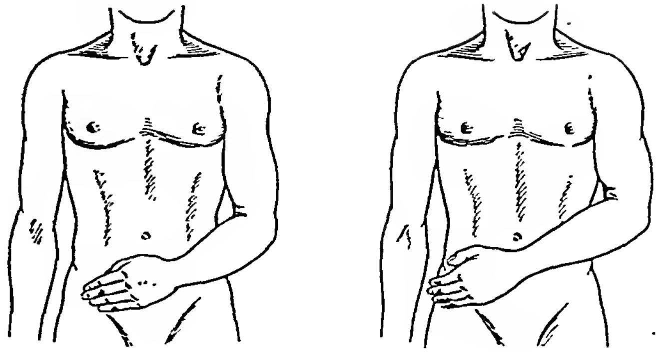
d: The hinge flap, which is made with healthy tissue, helps to give the main flap strong vascular connections, particularly when the latter is applied to a poorly vascularized area.

D. *The Length of Time Before the Separation of the Flap*

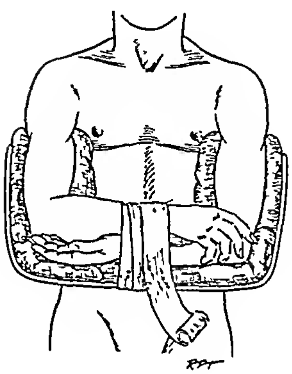
Under ordinary circumstances, flaps may be separated around the fourteenth day.



A

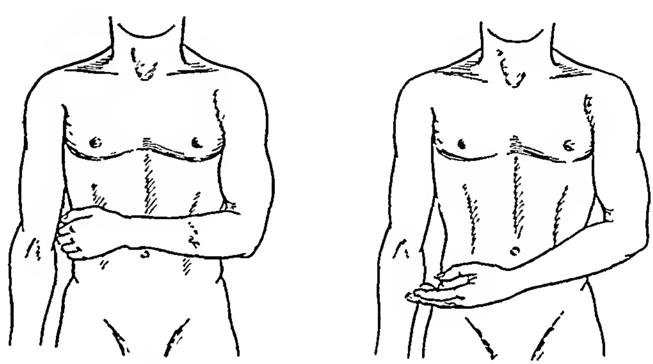


A B



B

Fig. 15



C D

Fig. 16

Fig. 15: Splinting in cross-arm flaps.
A: Typical position for the repair of the palm by a flap from the opposite forearm.
B: U-shaped splint, made with padded wire, immobilizing the upper extremities.

Fig. 16: Various positions for the transfer of abdominal flaps to the hand and forearm.

When conditions are unfavorable for the normal revascularization of the flap, as when the flap is placed over denuded bone, about twenty-one days should elapse before the separation of the flap. When the whole of the defect cannot be covered in one stage, the portion of the flap applied in the first stage must serve as the base for vascular supply of the whole flap in the second stage. It is prudent to wait twenty-one days before sectioning the flap, so as to permit the newly transplanted flap to acquire strong vascular connections.

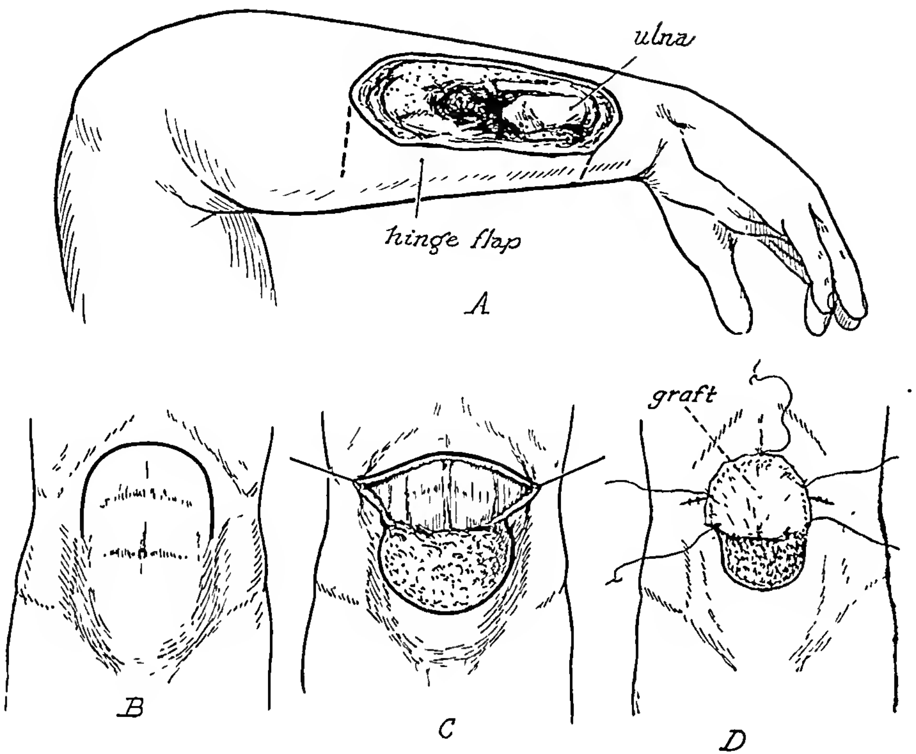
II. *Technique Particular to Certain Flaps*

A. *Flaps to the Upper Extremity*

Flaps to the upper extremity are of two main varieties: flaps transferred from one upper extremity to the other, or cross-arm flaps, and flaps transferred from the trunk to the upper extremity. One or the other of these flaps was used in the repair of the various segments of the upper extremity.

1. *Flap Repairs of the Hand and Forearm:*

In repairs of the fingers, the interdigital spaces, and the palm of the hand, the author has used cross-arm flaps, taken from the homologous upper extremity. In spite of the immobilization of both arms, this procedure is preferred in many cases, because the skin transferred is thinner, softer, and more pliable than abdominal skin. Figures 10, 11, 12, 13, and 14 show the various positions of transfer of such cross-arm flaps. In cross-arm flaps, a



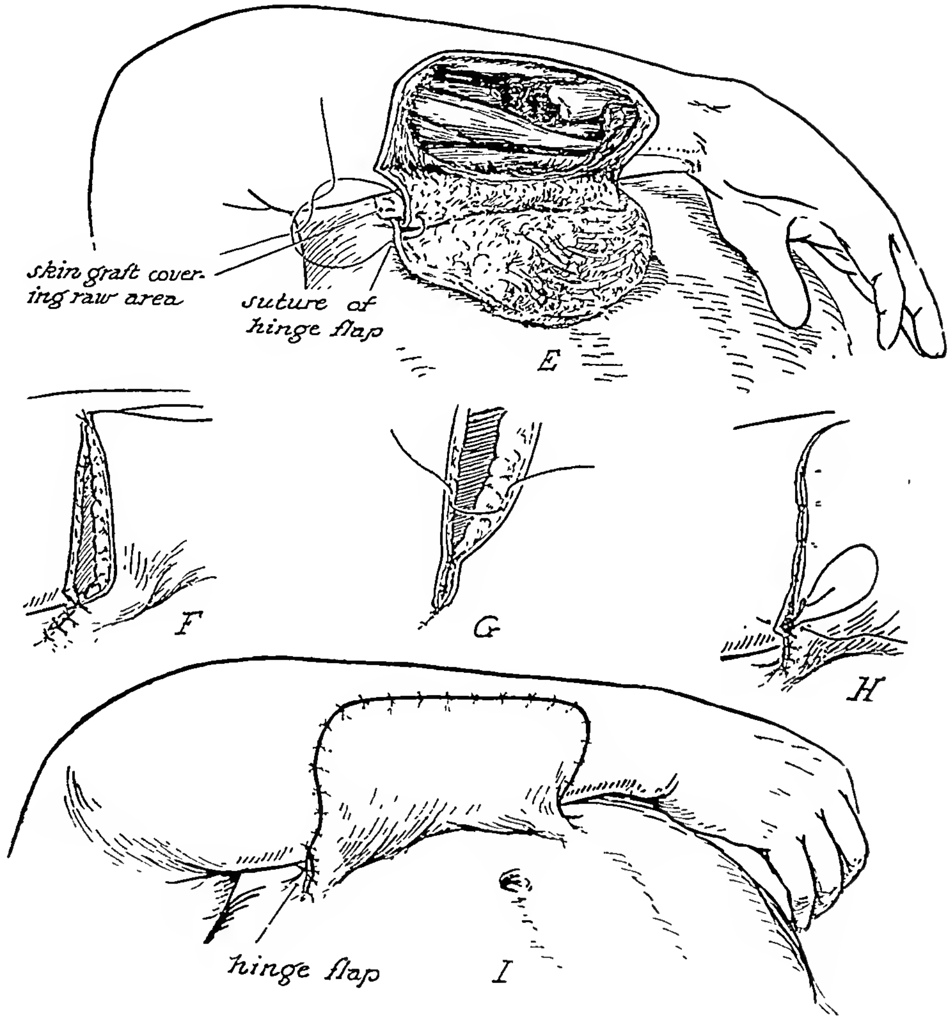


Fig. 17

Abdominal flap repair of a forearm defect.

A: Compound fracture of the ulna, osteomyelitis, sequestration, tendon necrosis, and loss of superficial tissue. Penicillin is administered. The wound is thoroughly excised and freed of necrotic and infected tissues. The hinge flap is outlined.

B: Outline of direct abdominal flap, made according to pattern of defect. The position of this donor area is less desirable than one situated in a lower abdominal quadrant.

C: The direct flap is raised. The lateral ends of the defect will be sutured, so as to diminish the area to be skin-grafted.

D: The skin-graft dressing has been sutured over the raw area. A tied-in pressure dressing will be applied over the graft.

E: The hinge flap is sutured to the base of the abdominal flap.

F, G, H, and *I:* Phases in the dermal and cutaneous suturing of the abdominal flap to the edges of the antebrachial defect.

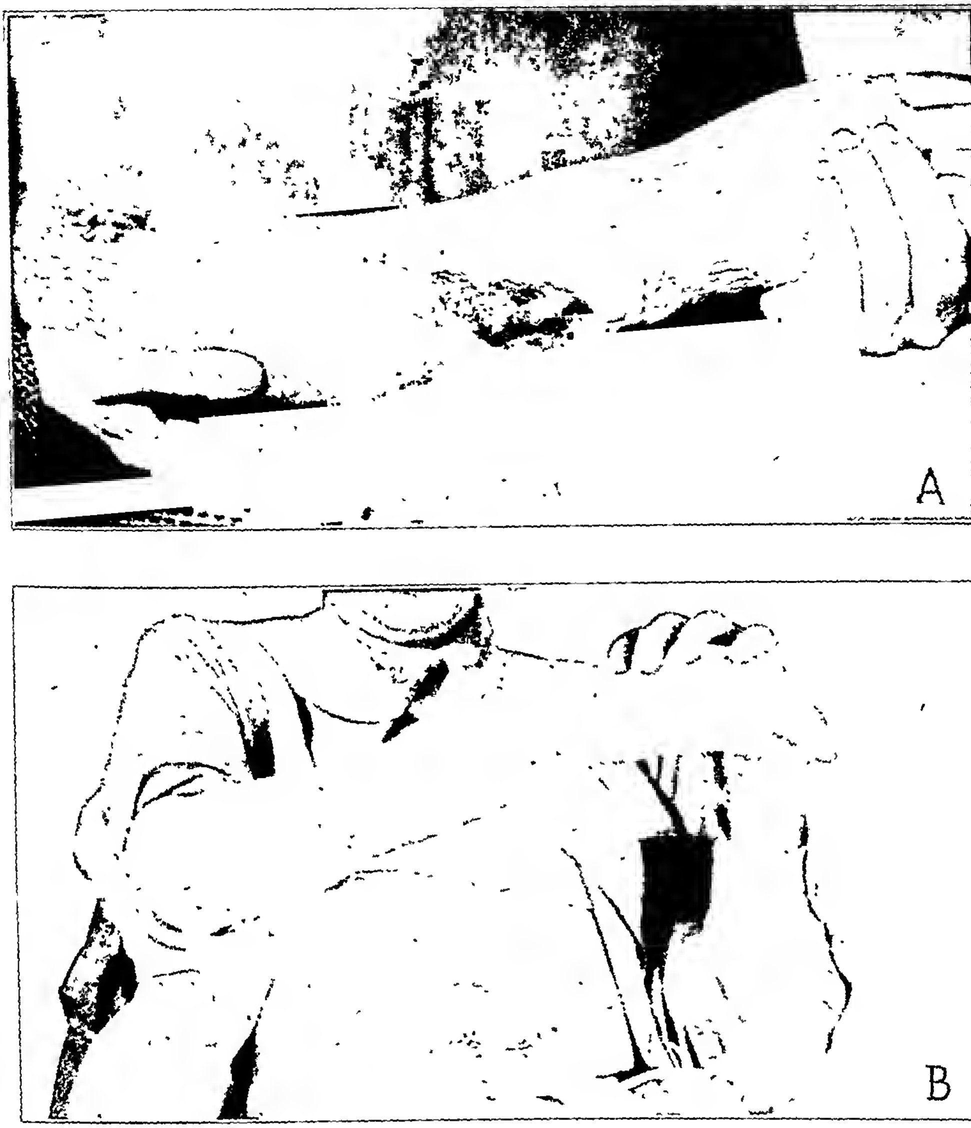


FIG. 18

A: Suppurating infected wound of the forearm, surrounded by area of scar tissue.
B: After transfer of direct abdominal flap, according to the technique described in Fig. 17.

U-shaped splint provides firm immobilization of the extremities (Fig. 15). Abdominal flaps have been used for the repair of defects of the dorsum of the hand, of the forearm, and of the elbow region (Fig. 16). The upper extremity is held against the trunk and immobilized during the transfer by adhesive tape and many-tailed bandages. Relaxation of the abdominal wall is obtained by elevating the patient's head and lower extremities. This position permits, in many cases, the direct suture of the abdominal defect. An abdominal flap may have the base of its pedicle above or below. Theoretically, a flap taken from the upper part of the abdomen should have its pedicle based above, so as to receive a blood supply from the branches of the internal mammary artery; a flap taken in the lower part of the abdomen should have its pedicle based inferiorly, so as to receive the branches of the deep epigastric artery. Practically speaking, the position of the base is determined by the site to be repaired. In defects of the dorsum of the hand and of the dorsal aspect and radial border of the forearm, an abdominal flap based above is used. In repairs of the volar aspect of the forearm and its ulnar border, a flap based inferiorly is applied (Figs. 17 and

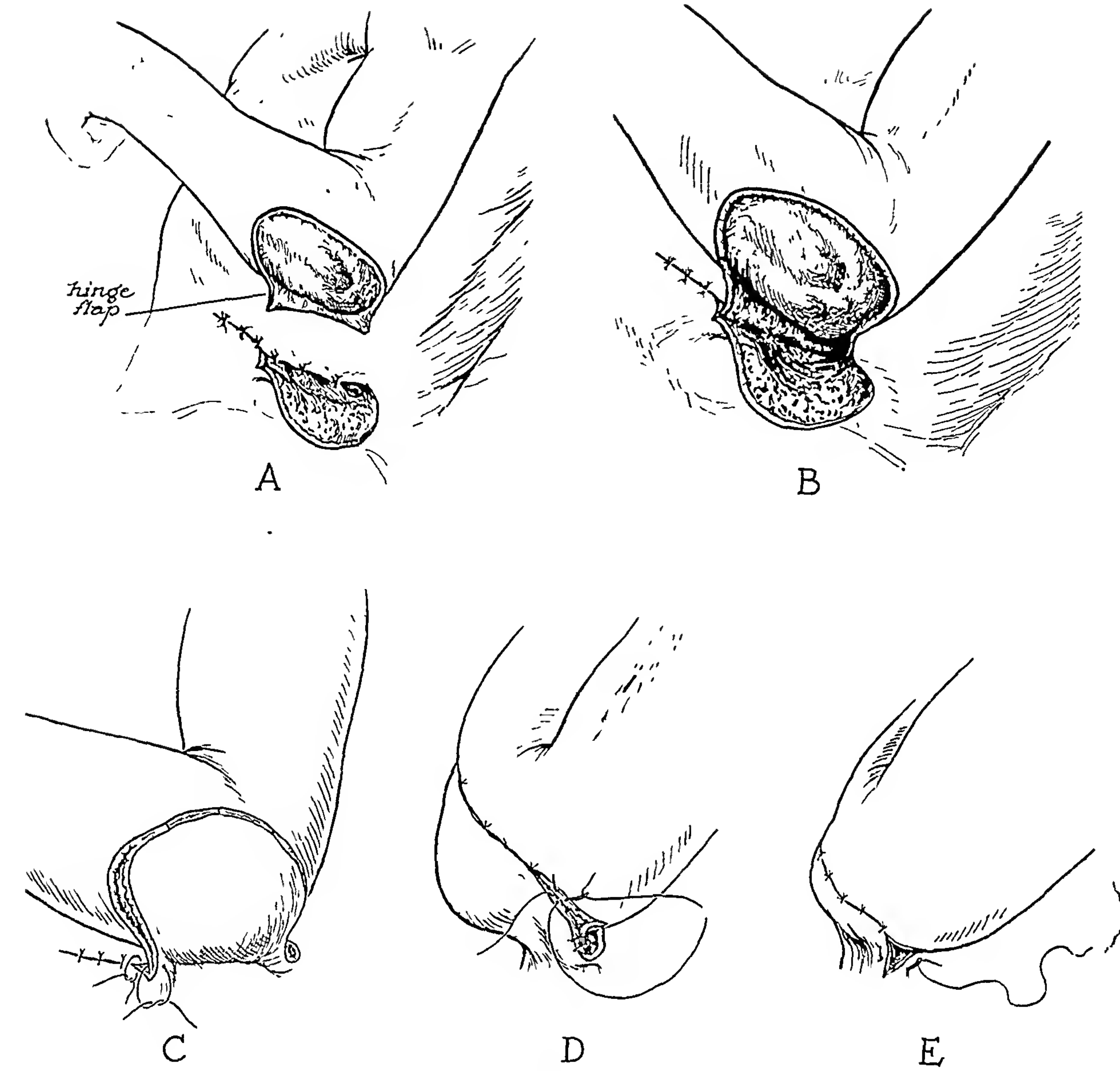


Fig. 19

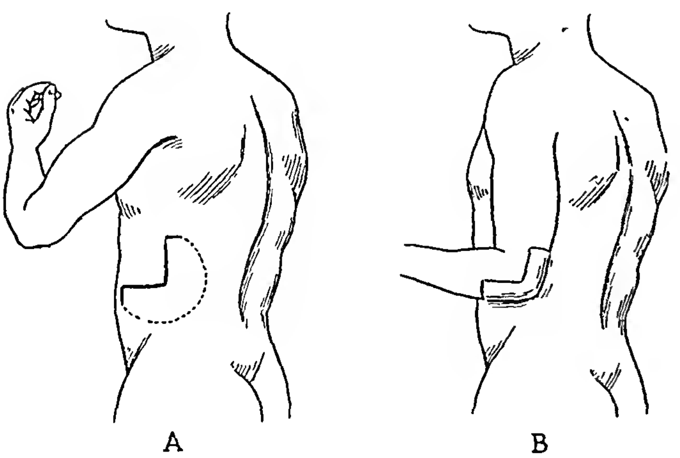


Fig. 20

Fig. 19: Direct abdominal-flap repair of the elbow.
A: The abdominal flap has been raised and the abdominal defect has been closed. The flap is ready to be applied to the elbow defect.
B: Suture of the hinge flap.
C, D, and *E:* Suture of the flap.

Fig. 20: Abdominal flap repair of the elbow.
A: Incisions at right angles delimit the flap, destined to cover the elbow region, when the joint is ankylosed in a 90-degree position.
B: The elbow is placed in a pocket, created by undermining the abdominal skin.

18). Abdominal flaps to the hand and forearm are often thick and usually necessitate subsequent thinning. A few weeks after the flap has healed, one half of the flap is raised, and a layer of fat is excised. The other half of the flap is left attached, so as to ensure the vascularization of the flap. A few weeks later, the same procedure is carried out with this latter half of the flap, which is thinned in the same manner.

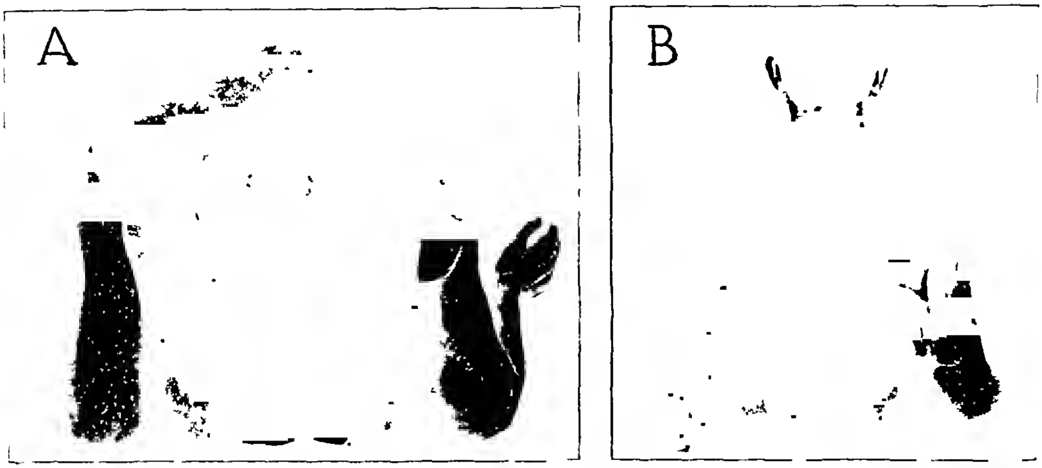


Fig. 21: A thoracobrachial flap.

A: Defect of the posterior medial aspect of the right arm. The patient presents an ulnar-nerve paralysis.

B: The thoracobrachial flap during transfer.

C: Satisfactory resurfacing of the arm. The ulnar nerve was sutured later.

Fig. 21

Fig. 22: *A:* Compound fracture of the elbow. A resection of the joint is necessary. Adequate soft-tissue covering must be provided.

B: A direct abdominal flap has been applied after complete excision of the scarred and infected tissues. Note the generous size of the flap and also the position of the upper extremity against the trunk.

C: The flap after healing. The donor area on the abdomen has been partly closed by direct approximation. The remainder of the defect has been skin-grafted.

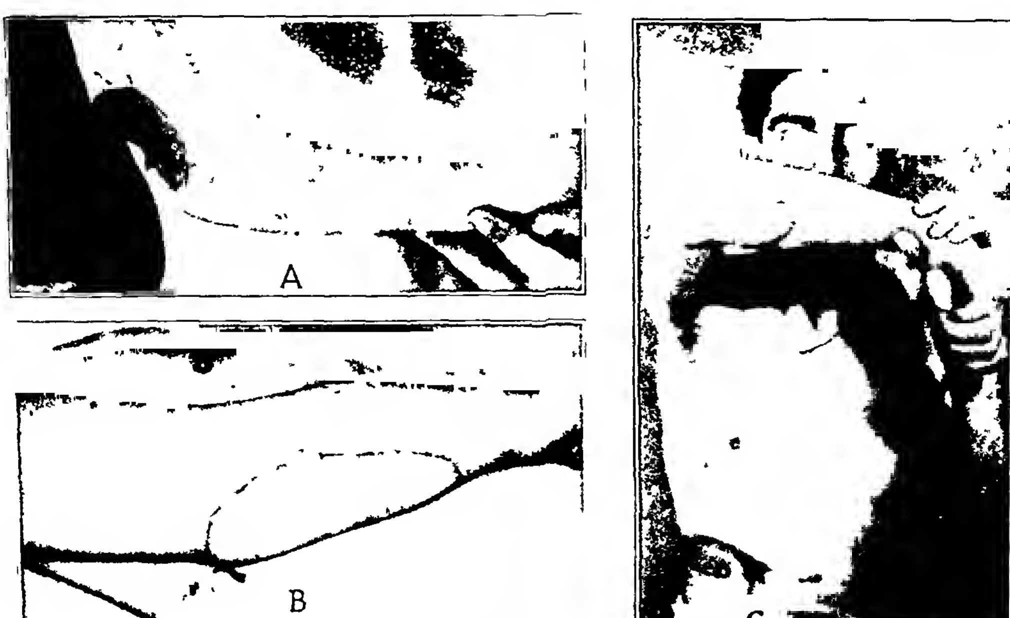


Fig. 22

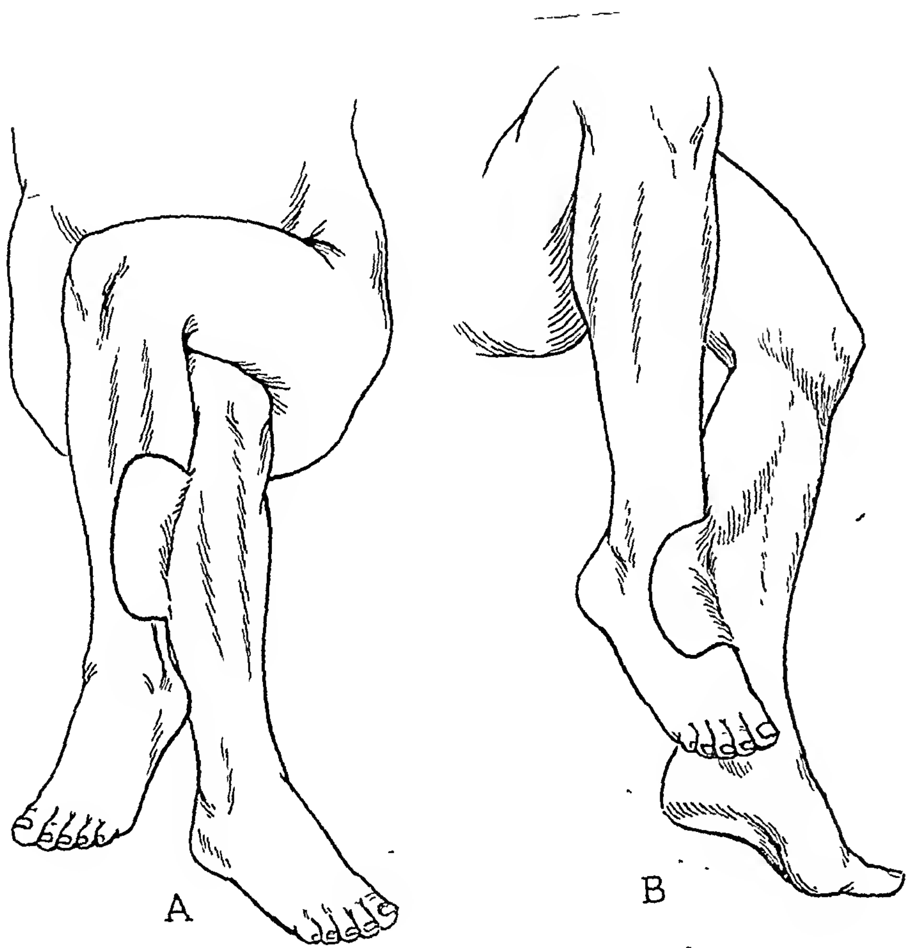


Fig. 23

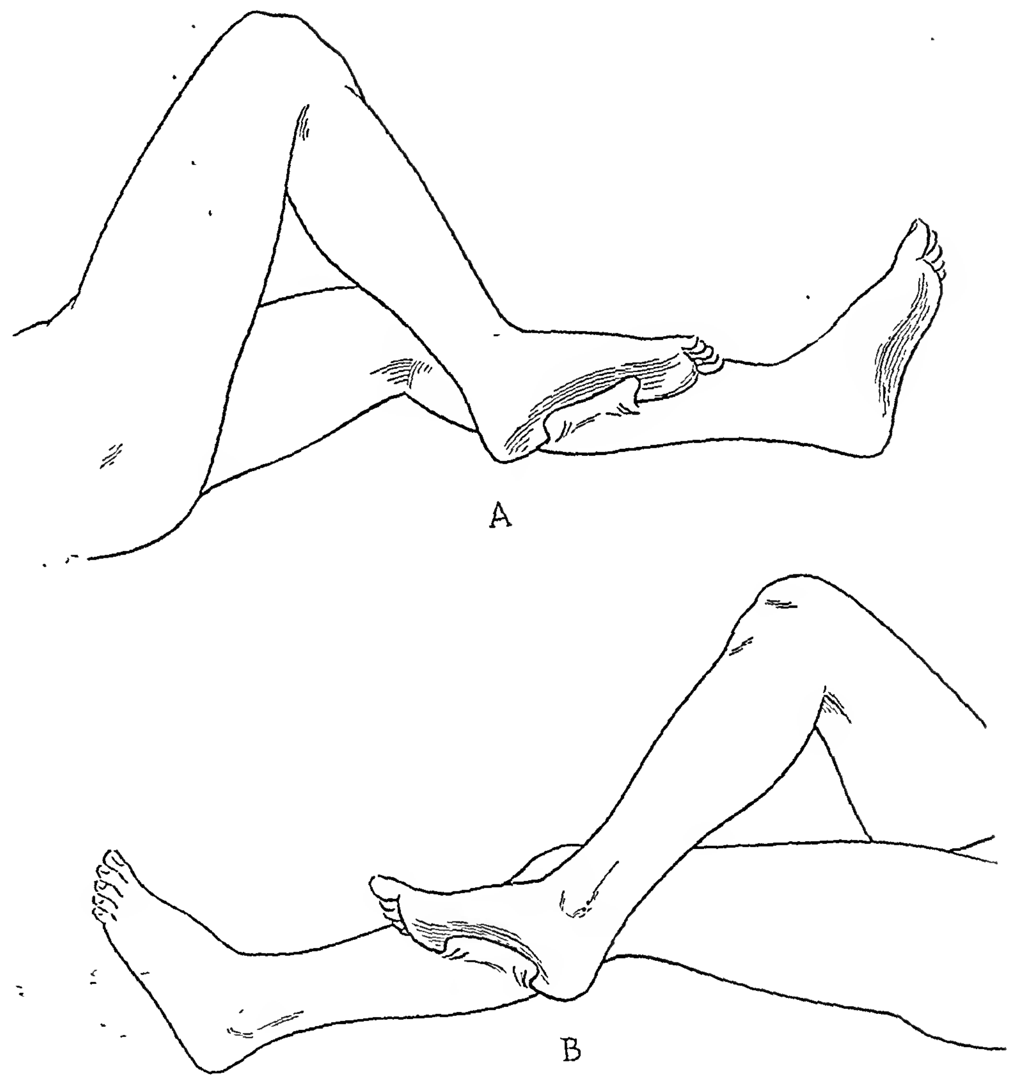


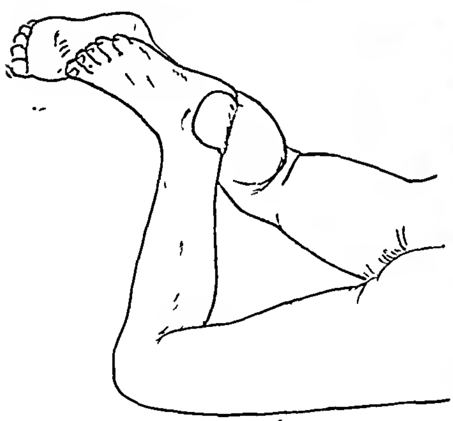
Fig. 24

Fig. 23: Positions for flap transfer from one lower extremity to the other.
A: The legs are crossed.
B: The legs are parallel.

Fig. 24: Positions of transfer for flap repairs of the sole of the foot.
A: Repair of the medial aspect of the sole.
B: Repair of the lateral aspect of the sole.

FIG 25

Suspension-elevation of the lower extremities after a cross-leg flap This position favors venous and lymphatic drainage and simplifies the nursing care of the patient



A

FIG. 26-A

FIG 26-B

Fig 26-A: Flap repair of the heel. Shows position of transfer of the flap for repair of the heel.
Fig 26-B: Similar position for flap repair of the posterior aspect of the leg

2. *Flap Repairs of the Elbow:*

For the elbow region, a flap raised just above the iliac crest is employed (Fig. 19). In the lower abdomen, the superficial fascia contains elastic tissue in sufficient abundance to comprise a separate stratum, the fascia of Searpa. Flaps taken from this region present a natural elasticity and are particularly suitable as a covering for a mobile region, such as the elbow. In repairing the medial surface of the elbow, a flap with a pedicle based above is used. When the lateral surface needs a flap repair, the base of the flap is placed inferiorly (Fig. 22). When repair is needed on both the lateral and medial aspects of the elbow, a flap based inferiorly is used to cover the lateral surface, and the olecranon is buried in a

Fig. 27
Flap repair of the sole of the foot. *A:* Wound with skin loss of the medial portion of the sole *B:* Repair by a flap from the opposite leg, as illustrated in Fig. 24,*A*.

pocket, produced by undermining the base of the flap (Fig. 20). The upper edge of the abdominal skin defect is sutured to the edge of the defect on the medial aspect of the elbow. In a second-stage operation, two or three weeks later, another flap, based upon the portion already inserted upon the lateral aspect of the elbow, covers the medial aspect.

3: *Flap Repairs of the Arm:*

Thoracobrachial flaps present relatively little discomfort during transfer. These flaps are based posteriorly for the repair of the posterior aspect of the arm (Fig. 21), and anteriorly for the anterior aspect of the arm.

B. *Flaps to the Lower Extremity*

Cross-leg flaps are usually performed to procure a skin covering to the bones of the leg or of the foot. The donor site for the flap is usually the posterior or the posteromedial aspect of the opposite leg, various positions of transfer

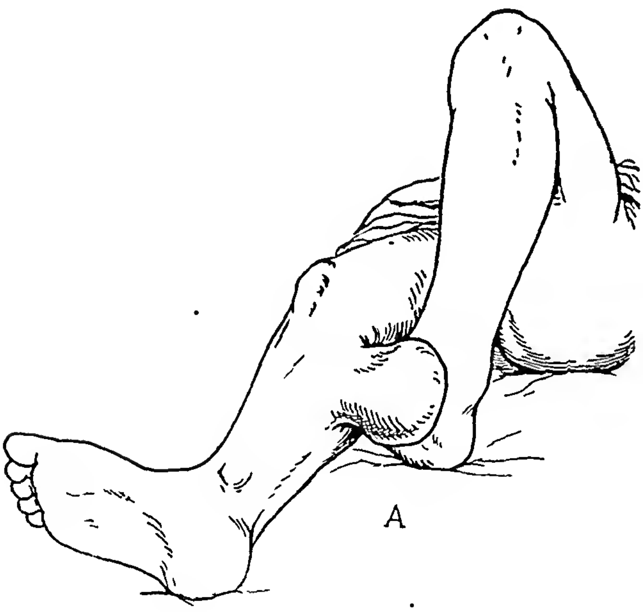


Fig. 28
Flap repair of the anterior region of the foot.
A: Position of transfer of the flap.
B: Aspect of the foot before the excision of an indolent ulcer and scar tissue.
C: Skin replacement by a flap of healthy vascular skin and fat.

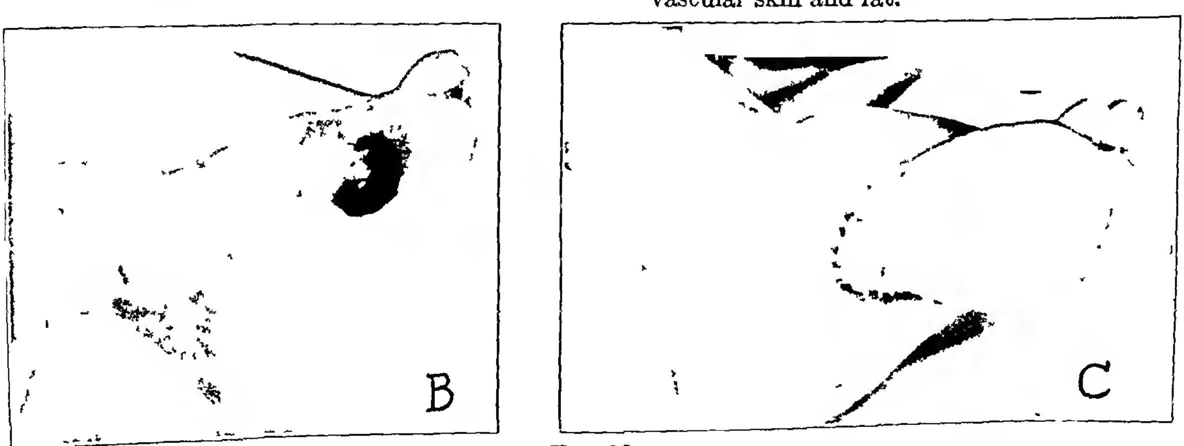


Fig. 28

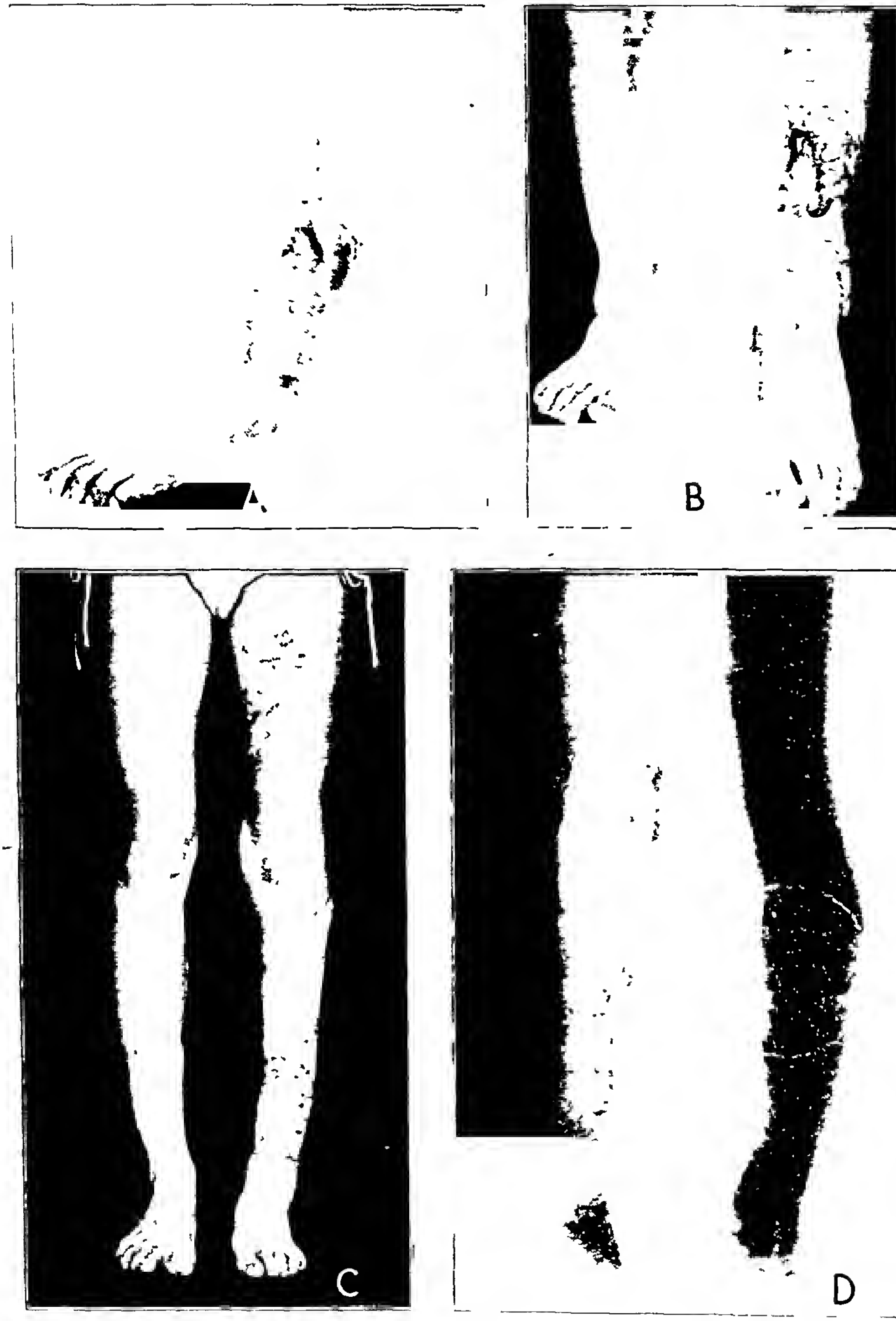


Fig. 29

Cross-leg flap over compound fracture of the left leg, with loss of soft tissue and of bone, resulting from a gunshot wound in a hunting accident.

A and *B* Aspect of wound of the left leg on May 14, 1946, eight months after the accident. Draining sinus, through which sequestra are eliminated, is surrounded by an area of infected and scarred tissue.

C Appearance on July 16, 1946. Defect has been covered by a cross-leg flap, taken from the posterior aspect of the right leg. Healed donor area on the left thigh is seen. Skin graft was removed to cover the donor area of the flap on the right leg.

D Aspect of donor area of the flap on the posterior aspect of the right leg. The skin graft of intermediate thickness has given a satisfactory resurfacing.

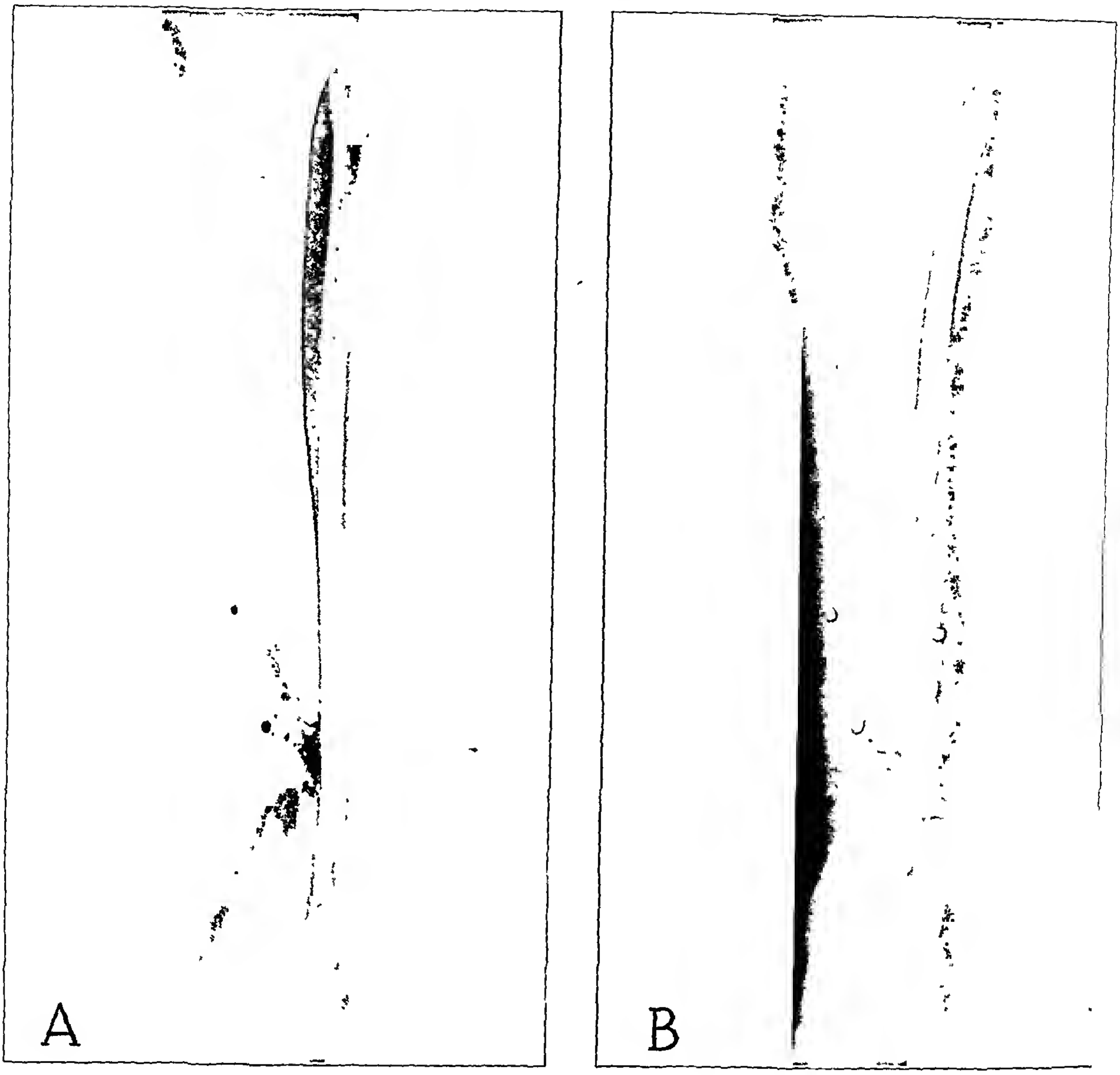


FIG. 30

A: Roentgenogram showing non-union of tibia with considerable loss of bone. Note hypertrophy of fibula with varus deformity of ankle (from weight-bearing in a brace). (Case shown in Fig. 29.)
B: After transplantation of the fibula into the tibia and filling in of the gap with iliac bone (operation by Dr. T. Campbell Thompson). Note correction of varus deformity of ankle.

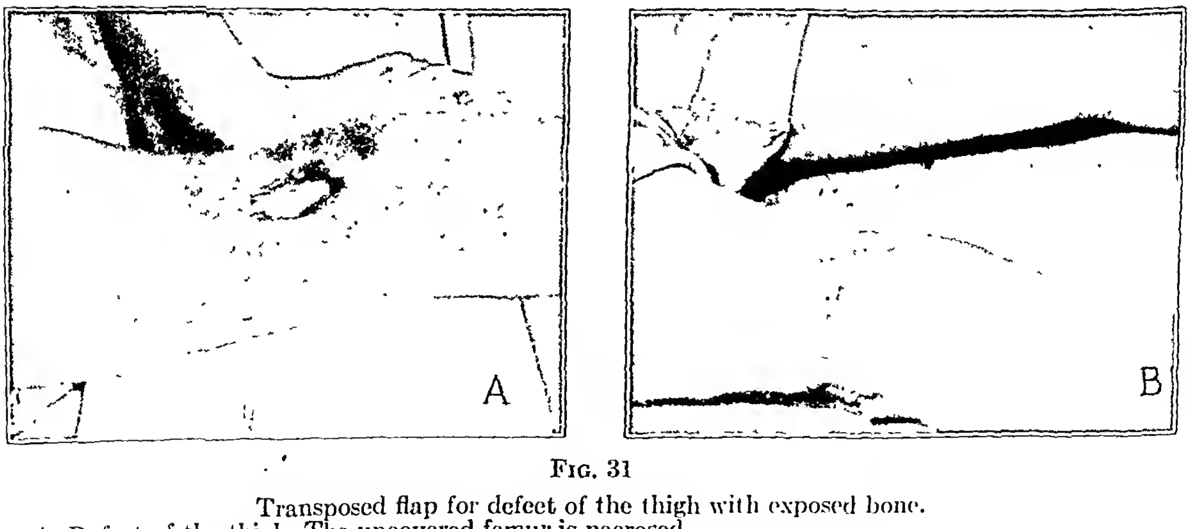


FIG. 31

Transposed flap for defect of the thigh with exposed bone.
A: Defect of the thigh. The uncovered femur is necrosed.
B: Complete closure has been obtained in one stage by complete excision of all scar tissue, resection of all necrotic bone, and covering the area by a transposed flap from the lateral aspect of the thigh The secondary defect was covered by a free skin flap over the fascia lata.

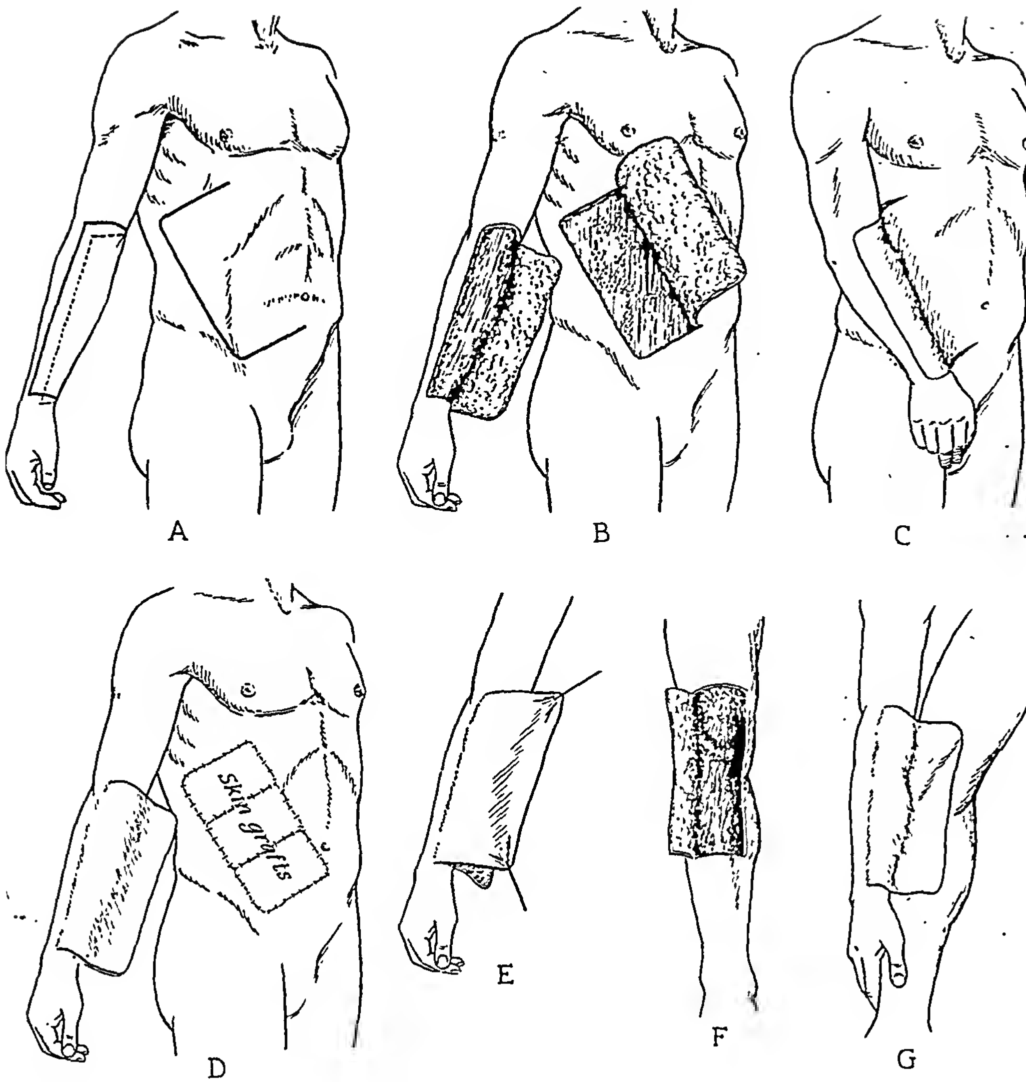


Fig. 32

The closed carried flap.

A: Outline of incisions for the abdominal flap and for the hinge flap on the forearm.
B: The abdominal flap and the hinge flap have been raised.
C: The abdominal flap is attached to the forearm.
D: The abdominal flap has been detached from the abdomen. The resulting raw area has been covered by skin grafts.
E: The carried abdominal and the antebrachial flaps are separated.
F: The scar tissue on the recipient area has been excised.
G: The carried flap is placed over the defect. The remainder of the carried flap will be detached from the forearm, in order to provide covering to the whole of the defect on the leg. The antebrachial hinge flap is then replaced in its original site, as in *A*.

being used,—the two legs are either parallel or crossed (Fig. 23). In a first step, the scarred area is widely excised, and a skin graft of intermediate thickness is removed from the thigh. In some cross-leg flaps, such as in the covering of a heel, the whole procedure can be performed on the patient lying ventrally (Figs. 26-A and 26-B). In most cases, however, it is necessary to turn the patient on the operating table, in order to prepare the flap on the donor leg and to suture the skin graft into place (Fig. 8).

After the pressure dressing has been immobilized by means of sutures, the patient is again turned, and the flap is applied over the defect. Interrupted U-shaped intradermal sutures are placed at regular intervals, so as to produce an accurate apposition of the edges of the flap to the edges of the defect, even without skin sutures, and even when the latter

are of unequal thickness. After the flap has been sutured in place, the lower extremities ar immobilized in their position of transfer by a carefully applied plaster. A table of th Hawley type facilitates this procedure. The wounds are not touched until, at least tw weeks later, the plaster cast is cut and removed, and the pedicle of the flap is sectioned During the period of immobilization in plaster, the extremities should be elevated (Fig 25). This position favors vascular and lymphatic circulation and simplifies the nursing care of the patient.

Various positions of transfer are used, according to the portion of the lower extremity warranting repair:

1. *Flap Repairs of the Foot:*

The covering of the distal portion of the foot (Fig. 28), of the dorsum, and of the heel, over the calcaneus or tendo achillis (Figs. 26-A and 26-B), is readily achieved by using the positions of transfer illustrated. More difficult is the flap repair of the sole of the foot, where the flap must be large in size and must heal *per primam*, so as to provide an unscarred pad of skin which will permit weight-bearing (Fig. 27). The repair of the inner half of the sole of the foot has been best achieved by an oblique flap, raised along the posteromedial aspect of the opposite leg (Fig. 24,*A*). For the transfer of a flap to the outer half of the sole, it has appeared preferable to cross the legs, taking an oblique flap from the posterolateral aspect of the opposite calf (Fig. 24,*B*).

2. *Flap Repairs of the Leg:*

In covering the anterior or medial aspect of the leg, a flap taken from the posterior region of the opposite leg should be used (Figs. 8, 29, and 30). The two legs are held parallel or crossed, whichever position permits the complete covering of the defect. When a flap repair must be carried out in the lateral portion of the leg, it is necessary to cross the extremities (Figs. 8 and 23,*A*).

3. *Flap Repairs of the Region of the Knee:*

A flap taken from the opposite calf will provide a covering, when a local flap taken from the thigh does not suffice.

4. *Flap Repairs of the Thigh:*

In the present series there has not been a single case of the use of a distant flap for a defect of the thigh. Local flaps from the generally abundant tissue of the region, combined with skin grafts, have been used (Fig. 31).

C. *Unusual Types of Flaps*

1. *Extensive Flap Repair of the Lower Extremity: The "Closed Carried Flap":*

By a method which we have called the "closed carried flap", rapid massive-skin covering of the lower extremity has been achieved in four cases. A summary of one of the case histories will describe this procedure:

A patient who had suffered multiple compound fractures of the right tibia twelve years previously, complicated by osteomyelitis, presented a densely scarred area, covering the anterior aspect of the right knee and of the right leg over an area of 12 by 17 inches. The scarred area was extremely unstable and, because of repeated breaking down of the area, was thickly fibrosed. Degenerative malignant changes were feared in the ulcerated areas. The knee was ankylosed in extension, and it was possible to raise the lower extremity without undue discomfort to the patient (Fig. 33,*A*).

In a first-stage operation, a right oblique abdominal flap whose undersurface was covered by a hinge flap from the right forearm was attached to the latter (Fig. 32,*B* and *C*).

In a second-stage operation, three weeks later, this closed flap was detached from the abdomen and carried on the forearm to the right leg, where it covered about three-quarters of the defect, from which the scarred area had been excised previously (Figs. 32,*F* and *G*, and 33,*B* and *C*).

In a third-stage operation, eighteen days later, the flap was sectioned, separated from the arm, and sutured to the remaining defect on the lower extremity.

Such a closed carried flap is a rapid method for the repair of defects of the leg, too extensive to be covered by a cross-leg flap (Fig. 33). Its application is limited, because of the discomfort occasioned by the position of transfer. Tubed pedicle flaps, migrated or carried from the abdomen, constitute the alternate method.

2. *Bipedicle and Multipedicle Flaps:*

In abdominal flaps to the hand and forearm which must extend from the palmar surface to the dorsal surface of the same hand, it is advantageous to be able to lengthen the flap by adding a pedicle.

A circular loss of the forearm may necessitate a skin-flap repair by a bipedicle flap. The flap is made to cover about three-quarters of the circumference,—the dorsal, medial, and lateral aspects of the forearm. The volar surface is applied against the abdominal wall. In a second stage, each pedicle is cut; sufficient length to cover the volar surface is allowed.

D. *Failures in Flap Transfers*

The failures which are met with in the course of the transfer of pedicle flaps may be due to necrosis, to infection of the flap, or to improper postoperative care.

1. *Failures Due to Necrosis:*

Necrosis of the whole flap or of a portion of the flap, generally the distal end, because of a deficiency in the blood supply, may be caused by various technical errors. The *proportions* of the flap may be such that the pedicle is not wide enough to permit the survival of a portion of the flap. A flap with sharp angles survives with difficulty. The size of the flap may be too small. In an effort to provide a covering to the defect, the flap is sutured into position under tension. Marked *twisting, kinking* of the flap, or placing the flap under *tension* may occur, either as a result of bad designing and planning of the flap, or because the position of transfer is inadvertently changed, when the immobilization of the donor limb is secured. This is a frequent complication during the application of a plaster for the immobilization of a cross-leg flap. To obviate this danger, the two limbs should be firmly immobilized on an orthopaedic table before the plaster is applied.

Not more than *moderate pressure* should be applied over a flap, lest the venous return be obstructed and superficial necrosis, blistering, epidermal desquamation, or even a loss of a portion of the dermis be the result. A frequent mistake in the covering of poorly vascularized areas is the employment of a *flap that is too small.* It is essential that the scar tissue of such areas be widely excised; and a flap that is to cover an area devoid of a normal blood supply should extend widely into the normal tissue around the defect. In this manner, the flap will derive a sufficient blood supply from the surrounding well-vascularized

FIG. 33

Repair of extensive scarred area of the right knee region and right leg by the "closed carried flap". Chronic osteomyelitis of the tibia had developed.

A. Respective positions of the right upper and lower extremities during the flap transfer.

B. Appearance of the carried flap during the transfer.

C. Aspect of the flap repair of the right lower extremity.

tissue. Failure to provide a wide area of insertion of the flap may result in necrosis of portion of the flap, when the pedicle is sectioned. Separation and gaping over the seconda suture line after the section of the pedicle of the flap were a frequent complication, when the flap was cut too small. The hinge-flap procedure assists in obtaining a vascularized base of insertion.

2. *Failures Due to Infection:*

Infection in the flap itself is rare, because of its resistance to infection, even when applied over a septic area. We have already discussed the preparation of wounds before the application of flaps. The covering of a grossly suppurating wound by a skin flap is generally a mistake. The flap acts as an obstruction to the drainage of a wound which should be left open.

3. *Failures Due to Improper Postoperative Care:*

After a successful flap transfer, there may occur complications, due to the imprudent treatment of the freshly transplanted tissue. This tissue has been severed from its nerve connections; it presents no sensation, nor do the inactive sebaceous and sweat glands provide the skin with its normal lubrication. The patient may unduly traumatize this insensible patch by exposing it to heat and burning. The burn sustained by laying the foot, newly covered by a flap, over a hot radiator is a typical complication. Even prolonged exposure to the sun's rays may cause desquamation of this already dry and scaly skin.

The vascular connections are delicate for weeks after transplantation; slight trauma may cause ecchymosis, hematomata, blistering, and ulceration of the flap. Due to the peripheral barrier of scar tissue, the venous drainage is sluggish and the lymphatic circulation is re-established only gradually. The venous return from the flap is improved by the wearing of a pressure bandage over the flap for months after the flap transfer. Massage will improve the circulation and hasten the softening of the peripheral scar. After the transfer of a flap to a weight-bearing area, the patient should avoid full weight-bearing for many months, until the peripheral scar has softened and a normal circulation has been re-established within the flap. Care should be exercised in placing secondary incision lines and in undermining flaps at the time of a subsequent operative procedure,—such as a bone-grafting. Necrosis of the flap may occur, if an incision is placed in the center of the flap and if the latter is undermined laterally. The flap is then left hinged upon lines of scar tissue, and the blood supply is insufficient. Furthermore, even if healing takes place without incident, the presence of three scar lines, instead of two, does not enhance the circulation of the flap. It is essential, on the contrary, that the secondary incisions be placed in former suture lines and that not more than one-half of the flap be raised, the other half being left attached to maintain the blood supply.

APPLICATIONS OF PEDICLE FLAPS TO THE COVERING OF BONE

The covering of bone constitutes one of the most important indications for the employment of pedicle skin flaps. Such flaps may be required for the covering of bone, denuded by the avulsion or the crushing of the overlying soft tissue; for the covering of fractured bones in compound fractures; and for the replacement of unstable, insufficiently protective, inadequately vascularized scar tissue for the resurfacing of areas of traumatic osteomyelitis and of bone cavities. A special application in this series has been the covering of the defect resulting from leg-lengthening.

A. *Early Covering of Denuded Bone*

The covering of unfractured denuded bone can often be carried out in the early stages by local transposed or rotation flaps. When the patient's condition does not permit a flap operation, or if the tissues in and around the wound are unsuitable for a flap, or if the

wound is too extensive to permit a local flap, a temporary covering can be obtained by the immediate application of a skin-graft dressing. At a later date, this skin graft can be replaced by a flap, either local or taken from a distance.

In compound fractures, when a flap operation is required, the suitable tissue for this procedure should be chosen. A discussion on the treatment of compound fractures is outside of the realm of this paper. Briefly, in compound fractures, the decision to execute an immediate pedicle flap will depend upon the type of wound inflicted. When the compound fracture is seen early, when a thorough excision can be performed, when no foreign bodies (such as earth or bits of clothing) have been pushed into the depths of the wound, the closure of the wound by a local flap, after the reduction of the fracture, followed by penicillin therapy, appears to be indicated. When such conditions do not exist, the flap operation should be postponed until the possibility of suppuration has passed, or until it has ceased. The closure by a flap of such an infected wound would only cause an obstruction to the surgical drainage of the wound and would lead to further necessary operative treatment of the wound. The problem of covering an extensive wound, requiring a flap from a distance, such as a cross-leg flap, is bound up with that of immobilizing the fracture. In such cases, an external skeletal-fixation apparatus was used until the flap transfer had been completed.* The external-fixation apparatus could then be removed and a plaster cast applied.

B. *Replacement of Unserviceable Scar Tissue over Bone*

The need for bone to be covered by well-vascularized tissue was well demonstrated in the present series by the spontaneous consolidation of six non-united fractures of many months' standing, after the transfer of a pedicle flap over the fracture site. Flap transfers were required to replace scar tissue over the heel and sole of the foot. Such scars not only were unstable, breaking down repeatedly under functional stress, but painful, because of the absence of the fat pad. Large flaps transferred by the cross-leg method, after wide excision of the scar, gave lasting repair. However, in weight-bearing areas, it was necessary to exercise great prudence before full functional activity was permitted, lest a breakdown of the flap occur. At least two months should elapse after the flap has healed, before the patient is allowed to walk. Normal activity should not be permitted until six months after the operation.

C. *Pedicle Flaps in the Treatment of Traumatic Osteitis and Osteomyelitis*

The successful treatment of traumatic osteitis and osteomyelitis is dependent upon the provision of an adequate soft-tissue covering of the bone. In the early phase, after the bone has been exposed by the avulsion, laceration, or crushing of the overlying soft tissues, one may be dealing with a simple osteitis, due to the necrosis of the cortex deprived of blood supply. The early resection of the devitalized bone and the immediate covering by a pedicle flap were followed by success in all of the eight cases of this series in which this condition was met.

In chronic traumatic osteitis and osteomyelitis, the following procedure was carried out: All of the necrotic and scarred soft tissue was widely excised, the sequestra were removed, and the devitalized-appearing bone was resected until normal-appearing bone was exposed. At this stage, the exposed bone must be covered by soft tissues, if further necrosis of the bone is to be avoided and a recurrence of invasive bone infection is to be prevented. For this reason, such areas were covered immediately with a pedicle skin flap. Accompanying penicillin therapy was instituted in all such cases. Most of the cases of chronic osteomyelitis seen had been treated over many months by conservative methods,—immobilization of the extremity, packing of the cavity with vaseline gauze, and removal of sequestra. In chronic osteomyelitis, there is often dense scar tissue over the bone. There

* The Roger Anderson apparatus was used in six cases.

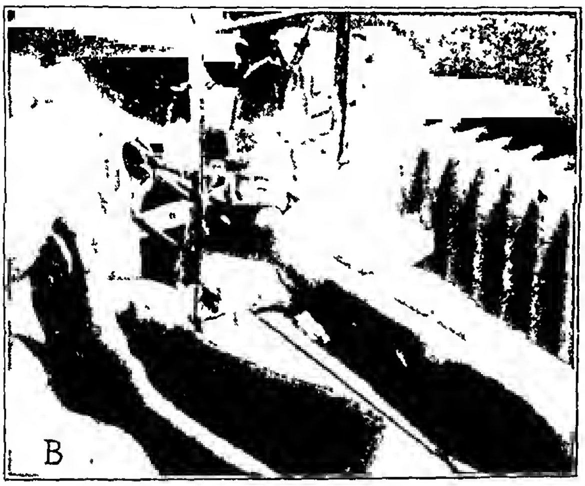


FIG. 34

"Accordion" flap for leg-lengthening.

A: Shortening of ten centimeters of the right leg followed compound comminuted fractures of the tibia and fibula, with loss of bone.

B: Lengthening of nine centimeters was obtained after excision of fibrous tissue, cross-leg flap (accordion flap), and traction. (Patient was treated in collaboration with Dr. Merle d'Aubigne of Paris.)

are two causes for this fibrosis. The first is that scar tissue is laid down in the granulation tissue which forms to cover the bone. Epithelium grows slowly over such granulations and, when the wound is an extensive one, the fibrotic changes, which appear in four or five weeks, may be marked [2]. The second cause is the fibrosis which is produced by suppurating sinuses through the skin. In ninety-eight such cases, a wide excision of all of the scarred skin and underlying fibrotic tissue was done; the devitalized-appearing bone was resected; and a flap covering of the area was made. In some cases, the suppuration, which had continued over a number of months, ceased only when this method was carried out.

D. *Pedicle Skin Flaps in the Treatment of Bone Cavities*

The covering of areas of bone presenting depressions, saucerized cavities, or cavities resulting from loss of bone through sequestration presents special problems.

Mention was made previously of skin grafts applied to bone cavities as a first step to obtain a healed wound. In a second stage, the skin graft was excised, and a pedicle flap was used to give permanent repair (Fig.9-C). The author feels that this first-stage skin graft may be dispensed with, and that a flap may be transferred immediately over a saucerized area.

In dealing with deep bone cavities, there may be a dead space between the flap and the bottom of the bone cavity in which exudate will collect. A draining sinus will often follow such an accumulation of fluid beneath the flap. The problem is to eliminate this dead space. When the cavity is not very deep, it may be saucerized to enable the flap to apply itself into the bottom of the cavity. When the cavity is too deep to be saucerized in this manner, it may be obliterated with bone chips. The bone lining the cavity is resected, until normal-appearing bone is exposed. The cavity is then tightly packed with bone chips, and covered by a skin flap. The preliminary temporary lining of such a cavity by a skin graft, to provide a healed dry wound, would appear to be good surgery. The skin graft is excised when the bone-grafting is done. However, in two recent cases, chip-bone-grafting of draining cavities, followed by a resurfacing by a skin flap, was successful.*

E. *Pedicle Skin Flaps in Leg-Lengthening: The "Accordion" Flap*

The following technique was used in three patients who had suffered shortening of the leg, as a result of loss of bone of the tibia and fibula and of soft tissue, following improperly treated gunshot wounds.

A flap of a special design, the "accordion" flap, was used to provide sufficient skin covering to permit leg-lengthening. All of the covering scar tissue was resected. The fibrous tissue between the fragments was excised, and immediate lengthening, varying from one

* In a recent case, treated in collaboration with Dr. P. D. Wilson, a draining bone cavity (5 by 4 by 3 centimeters in size) of the lower third of the tibia was successfully obliterated by chips of refrigerated homologous bone from the bone bank at the Hospital for Special Surgery. After the cavity had been filled with bone chips, a rotation flap from the lateral aspect of the leg was transferred over the area.

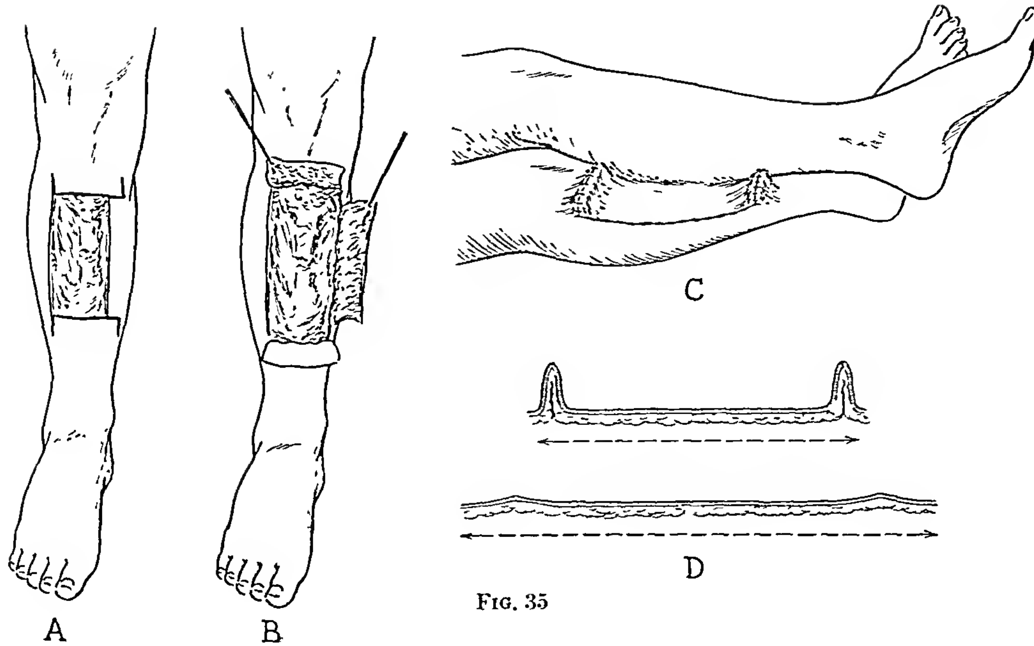


FIG. 35

Fig. 35: "Accordion" flap.
A: Outline of hinge flaps.
B: The hinge flaps are raised.
C: Accordion cross-leg flap in position.
D: Lengthening obtained by the accordion-flap method.

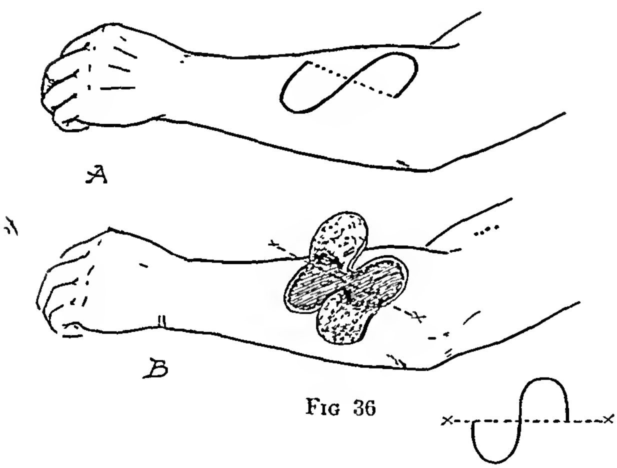


FIG 36

Fig. 36: S-shaped flap for simultaneous covering of dorsal and volar defects of the hand, following through-and-through perforating wounds.
A: Design of S-shaped flap.
B: The flaps are raised. The ulnar border of the opposite hand is placed along the line *xx*.

to three centimeters, was obtained by traction on the lower leg. Further progressive lengthening over a period of two weeks was achieved by continuous traction by means of a transcalcaneus pin. The problem of replacing the deficient soft tissue is twofold: A covering of the exposed bone must be done immediately, and subsequently the tissue thus transferred must be able to withstand the gradual lengthening of the leg, which in one case attained eight centimeters (Fig. 34). A reserve of cutaneous tissue was formed by designing and transferring the cross-leg flap, after raising three hinge flaps,—one medial, one superior, and one inferior (Fig. 35). This "accordion" flap permitted sufficient stretching to achieve the maximum lengthening of the leg.

THE APPLICATION OF PEDICLE SKIN FLAPS TO THE COVERING OF TENDONS IN RECONSTRUCTIVE SURGERY OF THE HAND

In traumatic lesions of the hand, aside from injuries to the bones and joints, the severance of tendons and the loss of skin covering are frequent. They generally result in the binding of the tendons by scar tissue, which prevents their normal play. The complete excision of all scar tissue is the first requisite in the liberation of the gliding structures of

the hand. This excision often results in extensive defects of the hand. The freed tendo must be covered by cutaneous and subcutaneous tissue, because they must be placed in medium of adipose tissue, which alone will permit their gliding. The presence of fat aro the tendon is the prime condition for the success of tendon surgery, whether it be simple freeing of the tendons, tendon sutures, or a tendon graft. When tendon-graftin necessary after wounds causing a loss of tendon substance, a preliminary flap repair of scarred skin may be necessary to obtain the complete mobilization of the finger joint l fore the tendon-grafting is performed at a later stage. When tendons have been sectione they can be strung through the fat with the Blair fascia lata needle. When this procedu is not feasible, longitudinal incisions can be made in the fat, the two lips of the incisio being brought around to surround the tendon. The complete insulation of the tendon by the adipose tissue of a pedicle flap may be insufficient, so that it may be necessary to cover the undersurface of the tendon with loose intercellular tissue, removed from over the fascia lata or over the triceps at the olecranon. A typical war injury is the through-and-through bullet or shrapnel wound of the hand. This lesion may result in a complete fixation of the hand, extensors and flexors being equally bound in scar. The one-stage freeing of all structures, volar as well as dorsal, and the covering of both surfaces of the hand by S-shaped flaps on the opposite forearm permit the gradual mobilization of the hand and, later, further reconstructive procedures (Fig. 36).

THE APPLICATION OF SKIN FLAPS FOR NERVE REPAIR AND SKIN REPLACEMENT, IN ONE STAGE

The necessity of plastic repair of the scarred cutaneous covering in peripheral-nerve lesions is well recognized. The usual procedure entails two separate stages; first the plastic repair of the scarred skin is carried out, followed in a second stage by the repair of the injured nerve. Thus a delay of weeks or months may occur before the nerve lesion is treated. It was observed that in a large proportion of such cases it was possible to perform the repair of the soft tissues and of the nerves in a single stage. After the complete excision of the cutaneous and subcutaneous scar and the liberation of all of the structures incorporated in the scar, the repair of the nerve is done. The surface defect is then covered by a flap of skin and subcutaneous fat, raised from the deep fascia and taken either from the adjacent area or at a distance. This single-stage combined operation presents the following advantages:

1. Less scar tissue is laid down in the wound than when two separate operations must be performed.
2. The date of the nerve repair is advanced, thus reducing the period during which progressive atrophy of the denervated end organs and muscles takes place. Recent experi mental work has stressed the importance of early nerve repair.

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THE FORMATION OF NEW BURSAE WITH CELLOPHANE*

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Fibroblastic proliferation is a reaction of normal tissue to trauma. This may be beneficial, as in the case of wound healing. It is undesirable when it leads to scar formation, especially when this scarring hinders the function of any part of the body. Operative trauma to a synovial surface is apt to be followed by adhesions. These may be overcome by early use of the affected part. However, if the operative trauma has been severe, or if the operation has included the excision of the synovial surface, the postoperative scarring may permanently limit the function of the part.

The purpose of this paper is to present the gross and microscopic studies of cellophane implantation into the sites of the subdeltoid bursae of rabbits, after these bursae had been obliterated by postoperative scarring.

Donati, in 1937, first reported the use of commercial cellophane, 0.02 millimeter in thickness, to prevent adhesions between the brain and the skull. After thirty-five days the cellophane was found to have no irritative reaction surrounding it. Wheeldon used cellophane in tissues, and was satisfied with the clinical results obtained. He had no postoperative gross or microscopic observations on the tissue reaction. He quotes a personal communication from Dr. A. W. Farmer of Toronto, who, in animal experiments, had noted no foreign-body reaction of the tissue to the cellophane.

McKeever used cellophane after synovectomy of the knee, in order to maintain the suprapatellar pouch. He obtained permission from a patient to re-explore his knee two months after cellophane implantation. He found a smooth, glistening tissue surface. He had used No. 300 P.U.T. and concluded that there was no tissue reaction to it. This was confirmed by microscopic examination. By the use of this method, flexion of the knee of 90 degrees was easily obtained by the end of the first week, with a minimum of effort on the part of the patient. Other types of cellophane may have a directly opposite reaction on tissues, and some observers have used this material in an attempt to stimulate the production of excess connective tissue.

Pearse, Harrison and Chandy, and Poppe and de Oliveira have used cellophane to cause obliteration or narrowing of aneurysms of the aorta and the subclavian artery. Harper and Robinson have employed cellophane to cause obliteration of a patent ductus arteriosus. Page and Graef reported the occurrence of perinephritis and hypertension. following the wrapping of one or both kidneys in cellophane. These authors wrapped either the aorta or kidney in cellophane of various types. It was sterilized by soaking in alcohol or mercury oxycyanide for twelve hours preoperatively.

Cellophane, in these cases, produced scarring. There was an immediate marked tissue reaction, which progressed to massive scarring in three to five weeks. Poppe explains the apparent contradiction in these two types of reaction to cellophane. There are chemically different types of cellophane produced commercially. These are varied still further by the application of many types of protective coatings, which add such qualities as moisture resistance and heat sealing.

MATERIALS AND METHODS

The site of the subdeltoid bursa was explored in thirty-five rabbit shoulders. These bursae had been obliterated by scar tissue, which had resulted from two previous operations, performed during the course of another experiment. The first operation consisted in

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traumatizing the floor of the subdeltoid bursa and the supraspinatus tendon. The second operation was performed to remove the supraspinatus tendon for microscopic examination. The end result was a complete obliteration of the bursa by scar tissue. It was decided that this scarred area would be a good area for testing the ability of an inert material, such as cellophane, to form a new bursa lined with a synovial surface. Accordingly, a third operation was performed, in which the scarred area of the subdeltoid bursa was dissected to form two layers. Between these two layers a sheet of No. 300 P.T. cellophane was placed. The roof of the bursa and the skin were then closed in separate layers, by the use of fine black silk.

The cellophane was sterilized by placing a sheet, about four inches square, between two heavy sheets of brown paper and rolling these to form a cylinder, which was autoclaved for twenty minutes. It was found necessary to employ heavy, smooth paper to prevent the cellophane from becoming wrinkled during autoclaving. At operation, circular pieces of cellophane, about one and five-tenths centimeters in diameter, were cut from the big sheet, and were used to separate the two layers of scarred tissue. No fixation was used, the cellophane being merely laid flat in the prepared site. The cellophane was left in the tissues for periods varying from 29 to 149 days, before being removed for study.

Intravenous nembutal anaesthesia was used routinely, supplemented by open ether if required. After the hair had been removed with sodium sulphide, neutralized with 15 per cent. acetic acid, the skin was prepared with iodine and alcohol.

OBSERVATIONS

Five of the operative sites became infected; so these rabbits were discarded, leaving thirty cases from which to draw conclusions regarding the effectiveness of cellophane.

Gross Observations

Twenty-three cases showed a bursa of normal appearance, one and five-tenths to two centimeters in diameter, lined with a shiny, glistening wall. The cellophane was as soft and as pliable as when it was inserted. In three of these cases there was no evidence of the cellophane, although a good bursa was present. It was thought that the cellophane had rolled up late in the process of bursa fomation, and had been extruded through the bursal roof and skin.

In five cases, the cellophane had become rolled up into a ball or a cylinder, and lay in a small sac, lined with a shiny, glistening wall. This sac was usually one to three millimeters in diameter. The sac containing the cellophane lay either in the position of the subdeltoid bursa or just beneath the skin. The pieces of cellophane which had become rolled up into a cylinder were those which were found just beneath the skin, having eroded through the roof of the bursa and the deltoid muscle.

In two cases no new bursa was found. In one of these no cellophane was found; and in the other, the cellophane was found as a tightly coiled cylinder, half extruded through the skin. It was pulled out easily, no force being required.

Microscopic Observations

Twenty-three sections showed a good synovial lining. Two, which were taken from a rabbit that had died the previous day, showed poor tissue outlines. A surface could be made out, but it was not clear-cut. In three sections the bursal surface was missed in cutting the block. The two cases in which gross examination disclosed no bursa formation showed, of course, no synovial surface microscopically.

The microscopic appearance of the newly formed bursae conformed very well to the description given by Key for normal synovial surfaces. In sections taken through the roof or floor of the bursa, the newly formed surfaces were typical of the areolar type of synovial surface (Fig. 1). There was a well-defined surface layer supported by loose areolar connec-

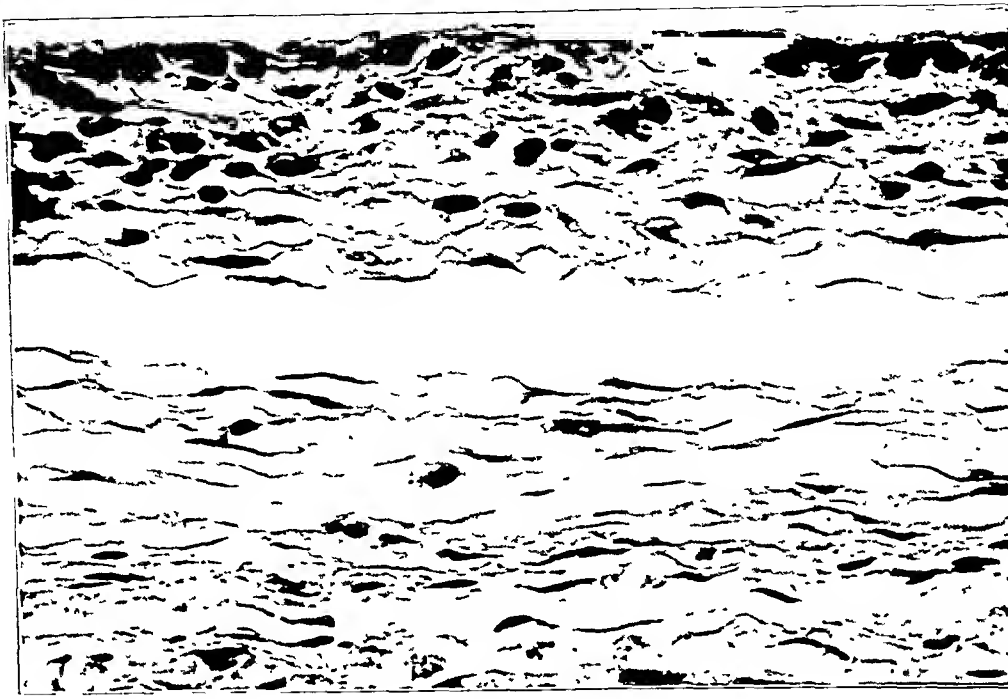

Fig. 1

High-power view (×400) of a newly formed synovial lining. There is a well-defined surface layer supported by loose areolar connective tissue. The cells lie in a collagen matrix. The nuclei of the surface cells are plump, while those of the deeper layers become more oval and, finally, elongated, with their long axis parallel to the surface lining.

Fig. 2

Villous formation. Villi show the same structure as the flat synovial lining. Some fibrin and occasional macrophages are also seen (×120).

Fig. 3

Cellophane *in situ*. The cellophane is seen as a relatively translucent band. There is no evidence of fraying or destruction of the cellophane. The newly formed synovial surface is seen lying on a base of denser connective tissue (×250).

tive tissue. The cells were imbedded in a collagen matrix, and lay either partially on or beneath the surface. The depth of this surface layer varied from one layer of cells to many layers. The collagen matrix varied from loose to slightly compact. Usually there were no villi present, but occasionally there were a few (Fig. 2). These villi were of the same structure as the flat synovial layer. The surface cells were flat, and lay imbedded in a loose collagen matrix. The deeper cells were more spindle-shaped, and lay with their long axis parallel to the bursal surface. On the surface of the synovial membrane, there was occasionally a thin layer of fibrin. In this layer there were apt to be a number of macrophages. Rarely a polymorphonuclear leukocyte was seen around the surface layer. Underneath the surface layer were a varying number of small blood vessels. Sometimes these were profuse, and sometimes almost absent. In several specimens the bursa was excised intact, to preserve the cellophane within the bursa (Fig. 3). In sections of these bursae, the cellophane showed up under the microscope as a definite, but relatively translucent, band. There was no fraying of its surface or any sign of fragmentation. The underlying synovial surface appeared as described. In several of the sections through the floor of the bursa, a denser type of collagen, forming the base of the bursa, was found. Figure 4 shows one of these sections, with the coiled cellophane lying within the bursa. This bursa had been excised intact, without being opened. The lining wall was smooth, in spite of the coiling of the cellophane. The linings which grossly appeared normal showed a good synovial lining under the microscope.

The only evidence of foreign-body reaction encountered was giant cells surrounding suture material, which was fragmented in the process of absorption.

COMMENT

In the infected cases, the infection was not due to foreign-body reactions, because, in three of the five rabbits with infected shoulders, a normal new bursa had formed on the opposite side. All presented the gross and microscopic picture of pyogenic infection.

McKeever has stated that he found evidence of fragmentation of cellophane in his study of one case. He used No. 300 P.U.T. cellophane. If one might draw an analogy, from the rapidity with which silk suture is phagocytosed in rabbits, it is probable that cellophane destruction would be much more likely, and more rapid, in rabbits than in humans.

Key states that synovial-membrane cells are fixed connective-tissue cells, which are modified slightly because of their position. He points out that the lining cells of joint and

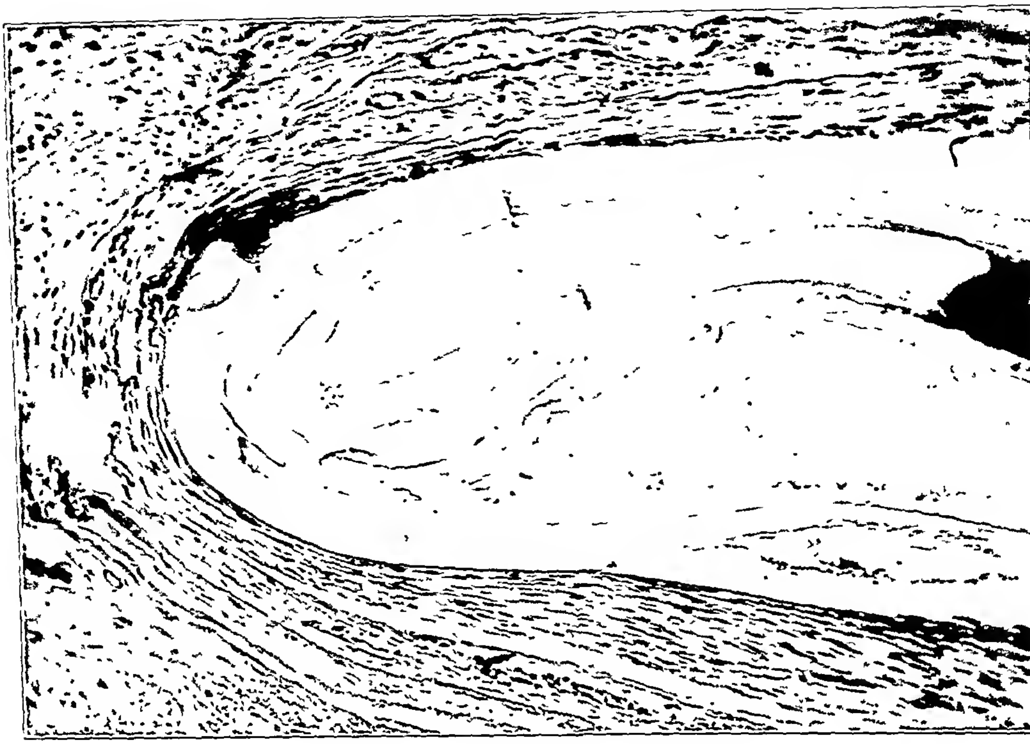

Fig. 4
Coiled cellophane lying in the bursa (×120).

bursal cavities differ embryologically from the cells lining the primary body cavities. This being the case, one would expect connective-tissue cells to be able to reform a synovial lining very similar to the original. The pictures reproduced here correspond closely with the normal specimens presented in Cowdry's textbook of histology, and also with the normal picture observed during this study.

Cellophane allowed the formation of a grossly normal subdeltoid bursa, with a glistening synovial lining, in twenty-eight out of thirty cases. In five of these, the size of the synovial cavity was diminished, due to folding of the cellophane. If a larger piece of cellophane had been used, or if it had been fixed at the edges so that it could not fold, this complication might not have occurred. That this synovial lining would not have resulted from simple dissection of the space and subsequent closure is evident from the fact that two previous operations resulted only in progressive scarring, and finally in complete obliteration of the subdeltoid bursa. It is quite possible that, if cellophane is used in human surgery, it should be removed through a small stab incision, after the new synovial lining has formed. The longest period of observation in these cases was 149 days. There was no sign of reaction of the tissues or degeneration of the cellophane. What would happen if it were left in human tissues for years is, of course, unknown. If the cellophane were excised through a small stab incision, and the bursa functioned in the usual manner, it would probably remain patent. In the three cases in which the cellophane extruded late in the process of bursa formation, there was no sign of subsequent obliteration of the bursa.

The cellophane extruded spontaneously through the skin by rolling up to form a cylinder, and pushed out by eroding the tissues with the sharp point so formed. This is another argument for fixing the edges of the cellophane to prevent it from rolling up to form a useless and potentially dangerous migrating foreign body.

Other writers have described a fibrotic reaction, following the use of 300 P.T. cellophane. Their technique has differed in two respects from that used in the present study. They sterilized their cellophane by immersion either in alcohol or mercury oxycyanide.

This may possibly have changed the chemical composition of the cellophane. They also wrapped the tissue in question in several layers of cellophane, thus partially occluding the blood supply. In performing experimental tendon sutures, the writer has not had very favorable results when the tendon was completely enveloped in a wide tube of cellophane. In this present study, the cellophane was laid flat between two opposing surfaces. The new synovial membranes so formed did not differ either grossly or microscopically from the normal synovial lining of joints and bursae. The cellophane in these experiments acted as an inert substance in the tissues.

SUMMARY AND CONCLUSIONS

1. Cellophane was effective in the formation of a new subdeltoid bursa in twenty-eight out of thirty cases, in which two previous operations had produced only scar tissue which had obliterated the bursa. In the two cases in which new bursae were not formed, the cellophane had coiled up and had been extruded.

2. Grossly, the new bursae were lined with a shiny, glistening wall. The cellophane lay in this new bursa with no gross evidence of foreign-body reaction in the tissues or of destruction of the cellophane.

3. Microscopically, the lining of these newly formed bursae differed in no way from the lining of normal bursae. There was no microscopic evidence of foreign-body reaction, or of fragmentation or destruction of the cellophane.

4. It is concluded that cellophane is a safe inert substance to use in the tissues. It will allow the formation of a new synovial membrane in areas where scarring is to be expected.

Acknowledgment is made to Dr. J. Albert Key for his valuable criticism and help in the preparation of this work, and also to Mr. Duane Taylor for his assistance in performing the operations and to Mr. K. Cramer Lewis for his photography.

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INTERINNOMINO-ABDOMINAL AMPUTATIONS

Report of Twelve Cases *

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The interinnomino-abdominal amputation has been in use, although not commonly, since its introduction by Billroth almost sixty years ago. His patient died a few hours after the operation had been completed, apparently as a result of shock. Girard, in 1895, is credited as the first surgeon successfully to perform an interinnomino-abdominal or hindquarter amputation. Since Billroth's case, approximately 130 cases have been reported in the literature. Prior to 1934, the operative mortality for this procedure was about 60 per cent. Since that time, the mortality rate has been less than 20 per cent.; this remarkable improvement is attributable to the use of transfusions and supportive measures[1]. Most of the reported amputations have been done for sarcoma. Tuberculosis of the hip early contributed a few cases, and other chronic infectious processes have been responsible for a few more. Metastatic carcinoma was found in one of Morton's cases, and the only fatality reported by King and Steelquist followed an amputation for rapidly spreading gas gangrene.

The first interinnomino-abdominal operation performed at the Mayo Clinic was in March 1943, and the second was in August 1943. A report of these two cases was published in 1944 by Ghormley, Henderson, and Lipscomb. One such amputation was done at the Clinic in 1944; two were done in 1945; and seven have been done so far in 1946, which brings the total to twelve.

The most common pathological condition encountered in this series of twelve cases has been the chondroma and osteochondroma group of tumors. These tumors, especially the non-pedunculated ones and those involving the bones of the pelvis, frequently have been difficult to eradicate. When they involve the hip, pain may be severe and the tumor may be small and hard to demonstrate. In the past, wide local excision was the accepted treatment; but it was found that the lesions almost invariably recurred. These recurrent tumors frequently grow rapidly and may attain great size. Malignant change has been reported when these tumors are not removed completely.[2] Of the twelve cases in this series, eight operations were performed for chondroma and osteochondroma, including Grade 1 and low Grade 1 chondrosarcoma and osteochondrosarcoma. Two operations were performed for osteogenic sarcoma and one each for myxofibrosarcoma and fibrosarcoma.

The operative procedure used in the twelve cases which form the basis of this report was essentially the same as that described by King and Steelquist. The method of making the flaps in one case was modified, because of the location of the tumor in the buttock. Another patient required a second operation for complete excision of the tumor, which filled the pelvis. This tumor was removed a month later.

Transfusions were carried out during each operation. The total amounts varied from 1,000 to 3,500 cubic centimeters. Two patients received an additional 500 cubic centimeters during the first twenty-four hours after the amputation. It has been apparent that several of these patients would not have survived the operation without the excellent assistance of our colleagues in the Section on Anaesthesiology, who gave the transfusions and supportive treatment.

* Read at the meeting of the Clinical Orthopaedic Society, Rochester, Minnesota, October 12, 1946.

Fig. 1

Case 3. Osteochondroma of right acetabulum.

Fig. 2

Case 4. Osteochondroma of right acetabulum and head of femur.

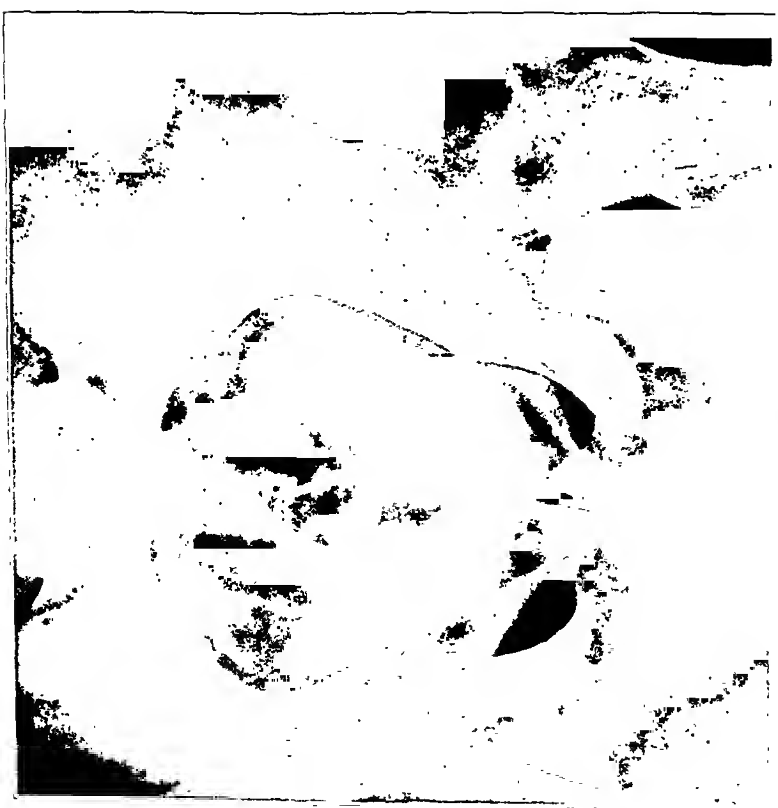

FIG. 3

Case 5. Osteoporosis of left ilium. Lesion later was proved to be chondrosarcoma, Grade 1.

FIG. 4

Case 8. Osteogenic sarcoma, Grade 4, of upper part of right femur.

Fig. 5

Case 9. Osteochondrosarcoma, low Grade 1, of right pubic bone.

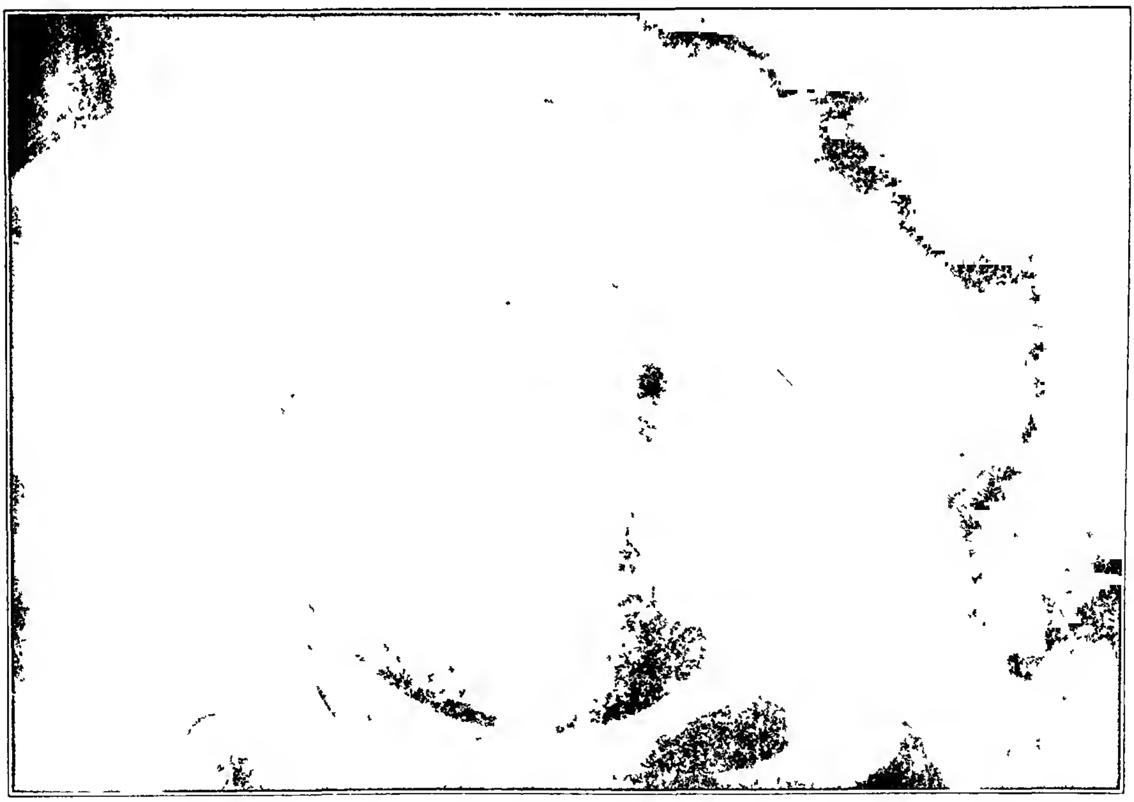

Fig. 6

Case 10. Chondrosarcoma, Grade 1, of left innominate bone in region of acetabulum, with extension into pelvis.

Convalescence was essentially uncomplicated. The majority of the wounds healed rather slowly. In two cases, infected hematomata developed, which healed promptly after incision and evacuation. In the case in which it was necessary to make the unorthodox skin flaps, rather extensive necrosis of skin ultimately required skin-grafting. The period of hospitalization ranged from twenty-one to ninety-four days. The shortest period was required by a boy fourteen years old, and the longest by the patient who had to have skin grafts.

All patients survived the operative procedure, and, by latest reports, are still alive. The entire series is probably too recent for proper evaluation. In Cases 1, 3, and 5, the lesion has recurred. One patient (Case 2) has been free of symptoms for three years. The other patients, with the exception of one (Case 4) who was well when last seen, were operated upon less than a year ago. These have been relieved of their pain and for the most part are satisfied with the result. The final evaluation must wait until a few more years have passed.

REPORT OF CASES

Case 1 (previously reported by Ghormley, Henderson, and Lipscomb). The patient, a man fifty-six years old, was first seen at the Clinic in November 1940. His chief complaint was pain in the upper part of his right thigh, progressive wasting of the extremity, and a limp. Examination revealed limited motion, mainly of rotation and abduction, adduction deformity, muscle atrophy, and diminished reflexes. The results of laboratory studies were within normal limits. Roentgenograms revealed nothing diagnostic. Physical therapy was given in an attempt to control the pain. The patient returned one year later; the pain and other symptoms had not changed. A comparison of new roentgenograms with the old showed evidence of diffuse spotting of the ilium and one region of slight periosteal change, suggestive of Ewing's tumor. Biopsy revealed proliferative villous type of synovitis.

When the patient returned in 1942, his pain was severe and he had been receiving narcotics for its relief. Roentgenograms at this time revealed a destructive lesion of the innominate bone. Another biopsy was performed and the pathologist reported finding a chondrosarcoma, Grade 1. A hindquarter amputation was advised, but the patient decided to wait. He returned and was operated upon March 13, 1943. His convalescence was uneventful, and the wound healed by first intention. When he was seen for his first check-up, he was relieved of pain, but local inoperable extensions of the tumor have developed since that time.

Case 2 (previously reported by Ghormley, Henderson, and Lipscomb). The patient, a man fifty-one years old, was first seen at the Clinic on March 23, 1943. He gave a history of fatigue and pain in the right thigh. He had walked with a limp for three months. Examination disclosed only atrophy of the right lower extremity. Roentgenograms revealed a cystic tumor, just above and adjacent to the right acetabulum.

On March 27, 1943, an exploratory operation was performed. A diagnosis of chondroma was made on the basis of pathological examination. The contents of the cavity were removed and the cavity was swabbed with phenol. The patient returned in July 1943, because of increasing difficulties. Roentgenograms revealed an increase in the size of the tumor. A hindquarter amputation was advised; this was performed on August 4, 1943. Drainage occurred from the wound, but healing was complete and prompt, after an infected hematoma had been evacuated. The patient was seen again in August 1946; he reported that he felt fine. No evidence of metastasis or of local recurrence could be found.

Case 3. The patient, a man fifty-nine years old, had noted pain in his right hip and a limp for about six months before coming to the Clinic, on April 19, 1944. Physical examination revealed atrophy of the right thigh and leg, pain on motion of the right hip, and a palpable mass deep in the right buttock, behind the acetabulum. Roentgenograms showed a destructive lesion of the right acetabulum (Fig. 1).

An exploratory operation and biopsy, on April 25, 1944, disclosed an osteochondroma. On May 1, 1944, a hindquarter amputation was performed. Convalescence was uneventful, except for delayed healing of the wound. The patient returned in April 1945, at which time a local recurrence of the tumor was found; this was excised. It was found that the tumor had also extended into the sacrum. Complete excision was impossible. When the patient was heard from last, in December 1946, he was bedridden, had severe pain, and required narcotics daily.

Case 4. The patient, a man forty-eight years old, was seen at the Clinic on March 23, 1945. He gave a history of pain in the right hip and around the right knee, present since December 1941. At first the pain was intermittent, but since early in 1943 it had been constant and had gradually increased in severity. On

physical examination, muscle spasm, with limitation of rotation and a flexion deformity, was found. The roentgenograms revealed evidence of osteoporosis of the head of the femur and in the region of the right acetabulum. There was also an area in the margin of the acetabulum, suggestive of an osteochondroma (Fig. 2). The possibility of a hindquarter amputation was suggested to the patient and, with his agreement, the region was explored on March 31, 1945. The diagnosis of osteochondroma was confirmed by the pathologist, and the amputation was performed. Convalescence was uneventful. The patient visited the Clinic again in November 1945, at which time he was free of pain. No evidence of recurrence could be found. A letter from the patient, in November 1946, reported that he was still well.

Case 5. The patient, a man thirty-eight years old, was first seen on February 11, 1942. His symptoms—pain and stiffness of the left hip—were of about six months' duration. The findings on physical examination were limitation of rotation, abduction deformity, and pain on motion of the hip. Roentgenograms showed evidence of osteoporosis of the bones of the hip and widening of the articular space (Fig. 3). Traction was applied, and the pain was somewhat relieved. The patient returned in July 1942, and the region of the hip was explored, but the hip was not dislocated to examine the inside of the acetabulum. A specimen was removed and the pathologist reported it to be fibrous inflammatory tissue. The patient again returned, and at rectal digital examination a mass was palpated on the inner wall of the left ilium. A diagnosis of cellular chondroma was made at exploratory operation, and the lesion was curetted out on March 3, 1945. The patient returned for re-examination in October 1945, at which time a recurrence of the tumor was found. A hindquarter amputation was suggested; this was carried out on October 22, 1945. Following operation, a hematoma developed in the wound; this became infected, but healed promptly after the hematoma had been incised and evacuated. When the patient was re-examined on May 14, 1946, he was free from pain. No evidence of recurrence was found. The patient returned again on February 6, 1947, at which time local recurrence of the tumor was demonstrated.

Case 6. The patient, a man sixty-one years old, was seen at the Clinic on January 3, 1946. He gave a history of pain below his right knee, which had been present since the preceding spring. In September 1945,

Fig. 7

Case 11. Osteogenic sarcoma in region of right acetabulum.

he had noticed a bump in the right groin which, after biopsy, was said to be cancer. He was given roentgenotherapy, but received no relief from the pain. The tumor continued to increase in size. On physical examination, the large, firm mass on the upper medial portion of the right thigh was readily palpable. The only abnormality found in the laboratory study was an elevated sedimentation rate. Roentgenograms showed the soft-tissue shadow, but no evidence of bony origin. A section of the tumor from the original specimen, removed for biopsy, was obtained for study, and revealed myxofibrosarcoma, Grade 2. As the only procedure available for complete removal of the tumor, a hindquarter amputation was advised; this was performed on January 16, 1946. The patient's convalescence was uneventful, except for slight drainage from the wound. On July 17, 1946, the wound was healed and no evidence of recurrence or metastasis could be found.

Case 7. The patient, a man fifty-three years old, was first seen at the Clinic on April 14, 1945. He complained of a painful mass in the right buttock: this had been present for about one and one-half years, but recently had grown rapidly. Physical examination showed normal findings, except for the rather large mass. Roentgenograms showed nothing more than the soft-tissue shadow of the tumor. On April 19, 1945, the tumor was excised. The pathologist's diagnosis was myxofibrosarcoma, Grade 3.

The patient returned in September 1945, because of local recurrence of the tumor, and was given roentgenotherapy. He returned again in February 1946, by which time the size of the recurrent tumor had increased. A hindquarter amputation was advised; this was performed on February 16, 1946. Because of the location of the tumor and the previous local excision, the usual posterior flap could not be utilized. In its place, a large anterior and medial flap was used. This sloughed rather extensively, and the defect required skin-grafting for closure. This prolonged the period of hospitalization. In a letter, dated September 5, 1946, the patient's wife reported that the wound was nearly healed, but that the patient still had severe pain and was unable to be out of bed for more than short periods. The patient revisited the Clinic on January 13, 1947, at which time he was free of symptoms. No evidence of recurrence or metastasis was found.

Case 8. The patient, a boy fourteen years old, was first seen at the Clinic on February 18, 1946. He had injured his right hip while playing football, in November 1945. There was little immediate distress, but he noticed that the hip was stiff and that the pain gradually increased. The hip had been immobilized in a spica cast for a month, without relief of pain. The patient had been confined to bed for several weeks.

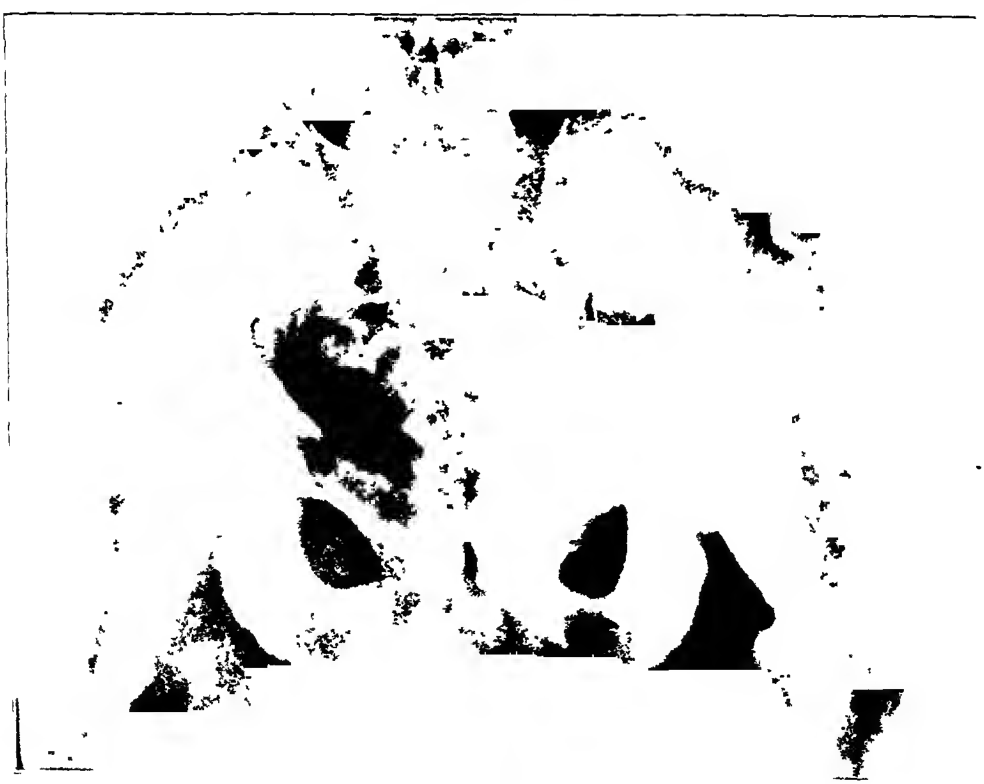

Fig. 8

Case 12. Osteochondroma of the left ilium.

Physical examination revealed a fixed, painful, and swollen right hip. Roentgenograms suggested that an osteogenic sarcoma of the upper end of the right femur was present (Fig. 4). Biopsy was performed on February 20, 1946, and revealed osteogenic sarcoma, Grade 4. In order to relieve the severe pain, a hindquarter amputation was advised; the operation was performed on February 25, 1946. Convalescence was uneventful. The patient was dismissed on the twenty-first day after operation. When he was re-examined, on August 1, 1946, he felt fine, had gained weight, and was walking with the aid of crutches. No evidence of recurrence or of metastasis was found.

Case 9. The patient, a man thirty-one years old, was first seen at the Clinic in January 1939. His chief complaint was gradually increasing difficulty in emptying his bladder and bowel. By roentgenographic examination, the physician in his home locality had demonstrated a tumor of the right side of the pelvis.

On physical examination at the Clinic, a large, firm mass was palpated over the right pubic bone and, by rectal examination, in the right side of the pelvis. Roentgenograms revealed a large osteochondroma, arising from the superior aspect of the pubic bone on the right side and extending well into the pelvis posteriorly (Fig. 5). On January 19, 1939, the right pubic bone and the tumor were removed. The diagnosis was confirmed by the pathologist. The patient was well for five years and then noted the gradual return of his difficulties. In October 1945, his right leg began to swell. His return to the Clinic, on April 15, 1946, was prompted by acute obstipation, lasting ten days. Physical examination revealed a tumor, filling the entire pelvis. Roentgenograms showed this to be similar to the original lesion. Laboratory studies disclosed nothing abnormal, and there was no evidence of metastasis. On April 25, 1946, the right hindquarter was amputated; in spite of transfusions of 3,500 cubic centimeters of blood, the shock was such that all of the pelvic and abdominal extensions of the tumor were not removed at this time. On May 30, 1946, by an abdominal approach, the remainder of the tumor was removed. The pathologist's diagnosis was osteochondrosarcoma, Grade 1. Except for slow healing of the incision, convalescence was uneventful. The patient reported by letter, on October 1, 1946, that he felt fine, and was back at work as a painter and decorator.

Case 10. The patient, a woman forty-two years old, was first seen at the Clinic on May 13, 1946. Her chief complaint was pain, which had gradually increased in severity for two years. Roentgenotherapy had given her no relief. Physical examination revealed a soft-tissue mass over the left hip and thigh; and, on pelvic examination, a firm mass was palpated on the left side of the pelvic wall. Roentgenograms gave evidence of an osteogenic malignant tumor, which involved the left innominate bone in the region of the acetabulum and projected into the pelvis (Fig. 6). The results of laboratory studies were within normal limits. A hindquarter amputation was advised; and the operation was carried out on May 23, 1946. The pathologist's diagnosis was chondrosarcoma, Grade 1. Convalescence was uneventful, except for a small hematoma under the flap. In a letter, dated October 1, 1946, the patient reported that she was feeling quite well, with slight pain only at night.

Case 11. The patient, a woman fifty-four years old, was first seen at the Clinic on May 17, 1946; she gave a history of right sciatic pain of one year's duration. Her condition had originally been diagnosed arthritis and treated as such, but subsequent roentgenograms revealed osteogenic sarcoma.

On physical examination at the Clinic, a tumor could be palpated on the inner surface of the right wall of the pelvis. Laboratory studies gave normal results. Roentgenograms revealed what was thought to be an osteochondrosarcoma of the right innominate bone in the region of the acetabulum (Fig. 7). A hindquarter amputation was advised; and this was performed on May 30, 1946. Pathological examination of the tumor revealed osteogenic sarcoma, Grade 2. Postoperatively, phlebitis developed in a varicose branch of the long saphenous vein in the remaining limb; this subsided promptly after the institution of dicoumarol therapy. In a letter, received October 6, 1946, the patient reported that she felt fine, with mild pain only at night.

Case 12. The patient, a man forty-three years old, was first seen at the Clinic in March 1944. In 1930, an osteochondroma had been removed from the region of the right hip. Recurrence was noted in this region in 1943, and the tumor had rapidly increased in size. The patient had a moderate amount of pain. This tumor (Fig. 8), including a large portion of the left ilium, was excised on April 3, 1944. Recurrence of the tumor was noted about a year later, and the lesion increased in size. Pain was not severe. On August 22, 1946, when the patient returned, the tumor was the size of a football. Roentgenographic examination revealed an osteochondroma, involving the remaining portion of the left ilium. A hindquarter amputation was advised, and this was carried out on September 11, 1946. The patient's convalescence was uneventful. His wound healed by primary intention.

COMMENT AND SUMMARY

Interinnomino-abdominal amputations have been performed in twelve cases at the Mayo Clinic. It may be claimed that the procedure is too radical to be used for benign

tumors. However, it has been found repeatedly that osteochondromata and chondromata frequently, if not invariably, recur after local excision, and eventually spread to the point where neither local nor radical excision is possible. In four patients, all of whom had fibrosarcoma or osteogenic sarcoma of a moderate to high grade of malignancy, this was the only procedure which would remove the lesion and offer any hope, slight as it might be. In Cases 1, 3, and 5, recurrences of the tumor developed which could not be operated upon.

One patient is well, three years after the operation. The operations on the remainder of the patients have been too recent for any long-range conclusions to be drawn. All of the patients have had a temporary respite from the pain, which has been a symptom common to nearly all of them.

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SENSORY DENERVATION OF THE HEEL FOR PERSISTENT PAIN FOLLOWING FRACTURES OF THE CALCANEUS

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In recent years, it has become increasingly evident that the prognosis in severe crush fractures of the calcaneus is generally bad. This has been the authors' experience. In a clinic receiving many traumatic cases, this fracture has come to be regarded as the "unsolved fracture". Similarly, Bankart has gone so far as to state that his results were "rotten", and he concurred with Watson-Jones in favoring immediate operations for fusion in the treatment of compression fractures of the heel, because of his dissatisfaction with the usual conservative measures.

Numerous methods of managing this fracture have been advocated. As has often been noted in other instances, multiplicity of solutions is usually indicative of discontent. In the hands of the authors, the treatment of the severe "squash" type of fracture, with comminution and involvement of the contiguous joints, has frequently been unsuccessful no matter what method has been used. Nor has triple arthrodesis served to improve materially the late results.

The reasons for these failures merit thoughtful consideration. Any speculation on this point would naturally start with the assumption that the more exact the reduction of the fracture, the better the end result. Hermann has shown the necessity of correcting lateral spread of the heel to avoid subsequent piling up of callus beneath the malleoli.

Böhler's insistence on restoration of the salient angle in the long axis of the calcaneus is well known. Others have emphasized the importance of the integrity of the subtalar and mid-tarsal joints. Despite all this, there are cases in which either the anatomical disturbances have been minimal, or the reduction has been excellent, and yet the patients have been left with disablingly painful feet. Conversely, some of the most severely crushed bones, producing shortened and flattened heels, have been practically symptomless. It is not uncommon to see this paradoxical state in cases of bilateral calcaneal fractures, with marked disparity between the roentgenographic appearance and the clinical status of each foot. Such observations cannot, of course, be explained on a psychological basis, and they have served to establish the conviction that correction of skeletal deformity is not the only objective in these cases.

For these reasons, it was believed that a different approach could be made to the relief of persistent disability following calcaneal fractures. It seemed that even the most severely crushed heel should not alter the integrity of the foot sufficiently to explain the marked symptoms wholly on structural grounds. Apparently, if it were possible to relieve pain permanently, there might be insufficient mechanical hindrance to satisfactory function. A physiological rather than an anatomical solution to this problem was, therefore, sought. Sensory denervation of the heel suggested itself as the answer.

Interruption of peripheral sensation for the relief of intractable pain in peripheral vascular disease of the lower extremities was introduced twenty-five years ago.[5] It is now an established procedure, with clearly defined indications and limitations [4, 6, 7, 8]. Its application, therefore, to the problem of the persistently painful heel after treatment for fracture is logical, direct, and technically simple. Actually, this procedure is readily adaptable to the traumatic foot, since concern over tissue viability, which is paramount in the case of vascular disease, does not pertain here, except in senile patients, who are not frequently involved in industrial accidents.

The tibial and sural nerves are the pathways for the type of pain encountered in these patients. Of these nerves, the latter is purely sensory, but the former also has motor branches to some of the small plantar muscles. There is no significant functional loss due to the division of these nerves. Sensation to the calcaneal region is supplied chiefly by the tibial nerve; the sural nerve's distribution of sensation is limited to only the lateral aspect of the foot. The tibial nerve alone transmits sensation from the joints contiguous to the calcaneus. Since division of this nerve results in anaesthesia of the entire sole of the foot, it would be of some advantage to section only its medial calcaneal branch, if that could be done. Isolation of these nerves is readily accomplished under local novocain infiltration. The technique of the operation has been previously described [4, 6, 7, 8]; in its essentials, this is the operation which was employed in the authors' cases.

Interruption of the sensory innervation of the heel was performed in seven patients.

Case 1. J. F., a truckman, aged thirty-five, was admitted to the Beekman Hospital on November 13, 1940, after having fallen three stories down an elevator shaft while at work. He sustained head injuries, fracture of the body of the first lumbar vertebra, and comminuted, compressed fractures of both calcanei. The heel fractures were reduced and managed in accordance with the Hermann method.

Fourteen months later, on January 20, 1942, the patient re-entered the Hospital. Despite anatomical correction and roentgenographic evidence of healing, he continued to have persistent pain in his heels, particularly in the left heel, when standing or walking. He had done no work since his injury.

Operation: On January 22, 1942, under local anaesthesia produced by 1 per cent. novocain, the tibial and sural nerves were individually isolated through two short vertical incisions in the lower third of the leg posteriorly. The nerves were readily found. After injection of a few cubic centimeters of 2 per cent. novocain into each nerve, the patient was found to have complete anaesthesia over the heel. Deep, as well as superficial, loss of sensation was proved by percussion with a wooden mallet. Since this preliminary procedure had indicated that anaesthesia could be obtained, the nerves were then compressed by hemostats, and two cubic centimeters of 95 per cent. alcohol was injected into each. The skin incisions were closed by fine silk.

Course: Relief of symptoms, following alcohol injection and nerve crushing, was complete but temporary. The patient returned to the Hospital two months later for nerve section (March 13, 1942). Under local

novocain infiltration, the scars from the original operation were excised, the nerves were exposed, and a segment of each nerve, about one inch in length, was removed.

Two months later the patient resumed his former occupation as a truckman. When last examined on October 2, 1945, about three and one-half years later, he stated that he had worked sixteen hours that day. He walked with a normal gait and had good ankle function. There were no trophic changes. Sensation had partly returned, but there had been no recurrence of pain when walking or jumping.

CASE 2. G. H., a stevedore, aged thirty-five, sustained a "squash" fracture of his left calcaneus on March 26, 1941, with marked lateral spreading of the bone. At the same time, he fractured the first lumbar vertebral body. Although fairly good anatomical correction of the calcaneal fracture was obtained, he continued to have persistent pain in the heel when walking, and he remained totally disabled on this account. On October 28, 1942, nineteen months after the injury, he was admitted to the Hospital for block of the peripheral sensory nerves.

Operation: Under local anaesthesia, the left tibial nerve was exposed through a linear incision made posteriorly, just above the level of the ankle. The nerve was isolated, injected with novocain and alcohol, and divided proximal to its medial calcaneal branch. The nerve was then reapproximated by means of fine perineural sutures through the neurilemma. In a similar manner, through a separate incision, the left sural nerve was exposed at this same level, divided, and resutured. In each case, the nerves were readily found, and the procedure was done without trauma to the accompanying blood vessels. Fine silk was used for ligatures and sutures.

Course: Follow-up examination was made on April 5, 1944, eighteen months after the denervation procedure. The patient had resumed work one year previously and had continued at his usual job. He still complained of numbness, which, however, was decreasing. He had no paraesthesia and no evidence of trophic disturbance. He walked with a normal gait and had a full range of motion in his ankle joint and foot. In October 1946, he was doing full-time work as a stevedore.

CASE 3. H. S., aged sixty-five, a laborer, entered the Hospital on May 31, 1943. Sixteen months previously, on January 19, 1942, he had fallen from a ladder, and had sustained compression fractures of both calcanei. He was treated elsewhere by manual reduction and plaster-cast immobilization, followed by a prolonged course of physical therapy. He was referred because of disability, due to persistent pain.

Examination showed moderate flattening of both heels, restricted joint motion, and a defective gait, due chiefly to pain on striking the heels against the floor. Percussion elicited sharp pain. Roentgenograms showed both calcaneal fractures to be well healed, with relatively little lateral spread; the tuber angles were satisfactory.

Operation: On June 1, 1943, the tibial and sural nerves in each leg were individually exposed, isolated, blocked by novocain, and divided. The nerves were not resutured.

Postoperative Course: From a condition of total disability, this man was subsequently returned to industry after sensory-nerve division. His result was regarded as satisfactory by the Federal Workman's Compensation Commission and his "schedule loss" was materially reduced.

CASE 4. J. C., a longshoreman, fifty-nine years old, entered the Hospital on January 31, 1944. In October 1942, he had sustained a fracture of the right calcaneus, for which he had been treated in another hospital by manipulation and plaster encasement, followed by months of care, although he was ambulatory. Bony union had taken place, but the patient had remained incapacitated because of pain in the injured heel.

Operation: On February 2, 1944, the right tibial and sural nerves were exposed, divided, and then reapproximated with sutures.

Course: Complete anaesthesia of the right heel area was obtained. When the patient was last examined in October 1946, sensation had returned without recurrence of local pain. There had been no evidence of trophic disturbance. This man had worked only irregularly since his operation.

CASE 5. J. S., aged forty-six, a longshoreman, was admitted to the Hospital on February 21, 1944, because of a painful right heel, resulting from an old calcaneal fracture. His injury had occurred eighteen months previously. Despite healing of the fracture and good anatomical position, disability was complete.

Sensory denervation of the right heel by division of the tibial and sural nerves was done on February 23, 1944.

Course: When examined two and one-half years after operation, the patient had partially regained sensation in the heel. Pain was not present on walking or striking the heel. He had not resumed work, due, apparently, to dissatisfaction with the legal aspects of his case.

CASE 6. N. D., a stevedore, aged forty-six, was admitted on February 27, 1945. Thirteen months before, while at work, he had sustained a compression fracture of his right heel. His pain had not been relieved by the usual conservative measures.

Section of the tibial and sural nerves was done on February 28, 1945, with excision of about two centimeters of each nerve.

When last examined in September 1946, he complained of paraesthesia in the heel and sole. There had

been some return of sensation, but he had no pain on walking or on direct percussion of the heel. No trophic disturbance had occurred.

CASE 7. M. K., aged forty-six, sustained a compression fracture of the left heel in addition to back and shoulder injuries when he fell into the hold of a ship, while working as a stevedore, on October 30, 1945. His calcaneal fracture was reduced by the Böhler technique. One year afterward, he was still totally disabled because of severe pain.

On November 1, 1946, nerve section was done, and segments of the left tibial and sural nerves were excised. Three months later, he had returned to work at a lighter job. He was entirely free of pain on walking and jumping. His gait was normal.

COMMENT

Seven patients were subjected to nerve section in an attempt to relieve intractable pain and total disability resulting from compression fractures of the calcaneus, sustained in industrial accidents. In all cases, the usually accepted methods of treatment—consisting of manipulative correction or attempted correction of the calcaneal deformity with subsequent plaster-cast immobilization, prolonged periods of rest, and, later, physical therapy—had previously been given adequate trial. In each instance an interval of over one year had elapsed after injury before sensory denervation was undertaken. These patients have been followed for periods of four months to five years after nerve section.

Four of the seven patients have returned to industry,—three to their former heavy occupations, and the fourth to lighter work. In three cases, disability has persisted; or at least these men have been unwilling to attempt work or to admit satisfactory results.

Experience with these cases has led the authors to feel that, while the full solution of this problem has not yet been found, the procedure suggested and tried may help to solve some of the difficulties encountered in fractures of this type. The results seem promising enough to recommend this procedure in certain instances. The selection of cases for this form of treatment should be made with care, and only after an evaluation, based upon the physical, psychological, and social factors peculiar to the individual, has been made. This procedure should be limited to cases of severe crush fractures of the heel, in which other methods have been tried and found inadequate. Furthermore, the patient must be one who has a sincere desire to "get well" and to return to his occupation.

No harmful effects were observed from peripheral-nerve section in any of these cases. No single evidence of trophic change occurred. This experience coincides with those previously reported. In fact, Smithwick and White, with regard to cases of thrombo-angiitis obliterans, have stated, "After an extremity has been desensitized, ulcerations which previously resisted all methods of treatment will frequently heal". The patient is warned of the necessity for cleanliness and is cautioned to avoid shoe pressure or friction. He is told of the peculiar sensation of numbness that will at first make walking seem strange, and he is cautioned to guard against injury. However, in all instances, sensation, wholly or in part, gradually returned without pain, and the only advice needed was to continue foot hygiene. As far as could be determined, there seemed to be little choice between nerve resection and simple division with resuture. Due to the peripheral site of the operation, it would seem best to remove a small segment of nerve to prevent too rapid recovery of sensation. This procedure is offered as a method of handling a problem that, in many instances, seems otherwise unsolvable at present.

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(*Continued on page 235*)

RESECTION OF THE OBTURATOR NERVE FOR RELIEF OF PAIN IN ARTHRITIS OF THE HIP JOINT

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The treatment of painful hip joints caused by destructive arthritic processes presents a difficult problem to the orthopaedic surgeon.

The purpose of this paper is to describe a simple method which produces relief of pain in a large number of cases, irrespective of the cause of the arthritic changes.

The method was first introduced in France in 1934 by Tavernier, following the procedure suggested in 1933 by Camitz in Sweden. Camitz observed veterinary surgeons performing resection of sensory nerves in the hoofs of horses, and thought of applying the same principle in the treatment of human hip joints. He was the first to report several cases.

Other surgeons in France then used this method of treatment, and they were apparently satisfied with the results. According to Tavernier, treatment consisted in an avulsion of the obturator nerve through an incision over the femoral triangle. The simplicity of the method and the reported relief from pain encouraged the author of this article to operate for the first time on a patient with severe Marie-Strümpell arthritis, involving the spine and both hip joints. The patient had been bedridden for about three months previous to the operation. On October 20, 1945, an avulsion of the obturator nerve through the femoral triangle of the right extremity was performed. The relief from pain was so satisfactory that the patient requested that the operation be performed on the left side. This was done in February 1946. The immediate results from both operations were excellent. Since then, the patient has returned to his occupation as a gardener.

The relief from pain obtained in this case prompted further operations, as well as a more searching investigation of the relation of the obturator nerve to the nerve supply of the hip joint.

The description of the nerve supply of the hip joint varies in the textbooks of anatomy and is incomplete. Neither is the relation of the obturator nerve to the capsule of the joint well described. Tavernier states that the deep branch of the obturator nerve supplies the greatest part of the anterior capsule of the hip joint, the head of the femur, and the acetabulum; and that the articular branches to the anterior capsule of the joint can be visualized in the cadaver and recognized upon operative intervention.

A personal study of the obturator nerve at its exit from under the horizontal pubic arch was made to clarify the problem. Dissection of the articular branches of the obturator nerve is technically very difficult, and requires fine and patient search with the aid of magnification. The articular branches of this nerve were examined on twenty-four cadavera, dissected by the more skillful first-year medical students at the College of Physicians and Surgeons, Columbia University, and also in thorough dissection of four hip joints by the author. Tavernier's description was confirmed to a certain extent. However, it could not be agreed that the articular branches to the joint capsule are easily seen. The illustration (Fig. 1), drawn from one of the specimens dissected by the author, shows the femoral triangle cleared of skin, fascia, and the large vessels and nerves of the region. The pectineus has been divided near its origin, and reflected outward. The horizontal branch of the pubis was resected to expose the obturator nerve in its course from the pelvis into the thigh. The pubofemoral part of the capsule was detached from the pubis, and reflected and rotated so that the antero-inferior part of the capsule is exposed. The largest articular

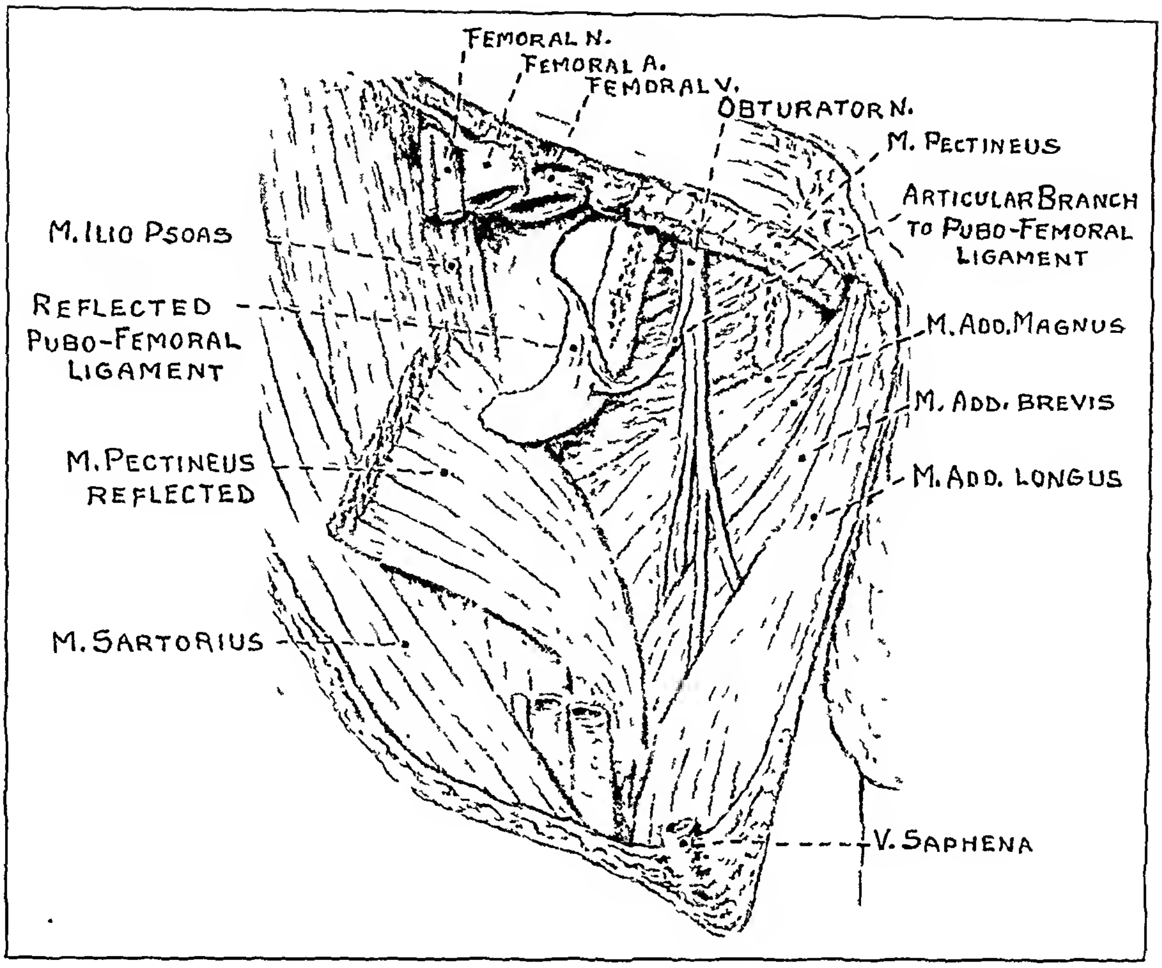

FIG 1

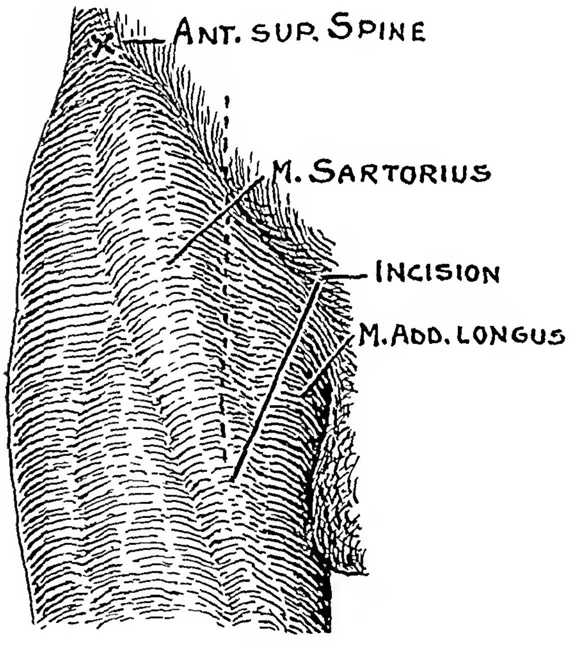

FIG. 2

branch of the obturator nerve originates from the common trunk, before its division into a superficial and a deep branch. Multiple slender articular branches are also found here. The superficial branch of the obturator nerve is seen to penetrate between the adductor longus and the adductor brevis. The deep branch enters the space between the adductor brevis and adductor magnus. Although this is the most common arrangement, the articular branches to the anterior capsule have also been seen originating from either the superficial or deep branch of the obturator nerve. The other articular branch, frequently described as entering the head of the femur through the round ligament, could not be followed.

The difficulties connected with dissection of the slender articular nerve branches are apparently responsible for the absence of clear information concerning the nerve supply of the hip joint. This nerve supply is generally described as consisting of anterior and posterior branches. The posterior branches arise from the sacral plexus, either directly or through the sciatic nerve, or from the posterior femoral cutaneous nerve. An additional branch is supplied by the nerve to the quadratus femoris. The anterior branches are sup-

plied by the lumbar plexus through the femoral and obturator nerves. Apparently the greatest part of the nerve supply to the joint is derived from the multiple branches of the obturator nerve.

Anatomical dissection showed that the easiest approach to the obturator nerve is through the femoral triangle (Scarpa's triangle). An incision, three to four inches long, is made parallel to the lateral border of the adductor longus muscle, which can be easily palpated, or may be found by connecting the pubic tubercle with the point of intersection of the sartorius, by a descending vertical line bisecting the inguinal ligament (Fig. 2). In the male patient, care must be taken not to divide the spermatic cord near the pubic tubercle. After the skin incision has been made, several layers of fat separated by superficial fascia are encountered, especially in obese patients. These fascial planes are divided, until the deep fascia covering the muscles of the femoral triangle is exposed. As soon as the deep fascia has been recognized, the long saphenous vein is retracted laterally. It should never be retracted medially, as it pulls with it the femoral vein. The saphenous vein may be ligated, if it is in the way. An incision is then made in the fascia, along the lateral border of the adductor longus. The space between the adductor longus and the pectineus muscle is easily found, and is separated bluntly. It may be observed at times that the pectineus muscle is overdeveloped, and hinders the exposure of the obturator nerve. It can easily be divided near its origin from the pectineal line. The separation of these two muscles uncovers a fascial space, usually filled with fat and crossed by vessels deriving from the obturator and the medial circumflex arteries and veins. Ligation of these vessels is a simple and rapid step. By gentle separation of the fat, the anterior branch of the obturator nerve is found and followed to the point of exit from under the superior arch of the obturator foramen. The identification of the articular branches is apparently very difficult. It is best to follow the nerve to the point of exit from the foramen, divide it, and avulse it as high as possible in a manner similar to that followed in phrenicectomy. The avulsion involves the two branches of the obturator nerve. No special closure is necessary. A few sutures in the subcutaneous tissue and skin are all that are required.

Of course, it is possible to approach the obturator nerve through the suprapubic route as described by Chandler, or through a medial incision between the adductor longus and gracilis muscles.

However, as many of the patients with arthritis are in the middle-age group, and are frequently obese, the suprapubic approach is involved and difficult. The relation of the obturator nerve to the artery and veins at the point of its penetration into the obturator foramen from the pelvis is quite inconstant. In the attempt to reach the nerve through the suprapubic opening, injury to blood vessels is possible, and difficulty in controlling bleeding may be very great. This is especially true in an elderly patient with arteriosclerosis. An additional incision is necessary if an adductor tenotomy is required. The approach between the adductor longus and gracilis does not represent a direct route to the exit of the nerve from the obturator foramen into the thigh, or to the extensive network of vessels usually found under the adductor longus.

In the author's experience, the anterior route is undoubtedly the simplest.

Following the first successful result and the anatomical study of the region, fifty-three patients were operated upon according to this procedure, by the author and other surgeons at the Hospital for Joint Diseases.

The cases were selected mostly for relief from pain in the presence of arthritis, irrespective of cause, and the results were considered good when pain disappeared, and when the patient could walk better after operation. The results were considered satisfactory when the pain diminished sufficiently to permit the patient to walk.

To determine the possible effect of the resection of the obturator nerve before the operation, an injection of novocain into the obturator nerve was given. The procedure of the injection is simple. The patient is placed flat on the back, and the affected extremity

is abducted to stretch the tendon of the adductor longus. A 22-gauge needle, two inches long, is then introduced near the origin of the adductor longus, close to its lateral border, and is pushed down to the horizontal ramus of the pubis. As soon as the bone is reached, the point of the needle is deflected down under the horizontal ramus and is pushed one or one and five-tenths centimeters into the foramen. Ten cubic centimeters of 1 per cent. novocain without adrenalin is injected. If relief from pain is obtained after the injection, the operative resection of the obturator nerve is considered advisable.

The following postoperative observations were made in the majority of successful cases: As soon as the patient recovered from the operation, the disappearance of pain was noticed. On the day following the operation, the patient was able to get out of bed. Examination of the extremity operated upon did not disclose any sensory disturbances over the inner aspect of the thigh or knee. In most of the cases, there was no anaesthesia and seldom any hypo-aesthesia in this area. If previous to the operation there was no severe deformity, the patient was able to walk with greater ease, as soon as the operative wound had healed. Active adduction remained normal, and was rarely even slightly weakened. But, even if preoperative flexion contractures existed, the pain was eased, and walking was more comfortable. In a certain number of cases, the pain disappeared for months, but recurred later. In cases where there was no relief immediately after this operation, patients required other surgical procedures.

Roentgenographic examination of the joints after resection of this nerve did not show any changes suggestive of trophic disturbances in the acetabulum or head of the femur either immediately after the operation or at subsequent dates.

Of the fifty-three patients operated upon, three patients had a bilateral avulsion of the obturator nerve. The others had an avulsion in one extremity only. Ten patients had excellent early and late results. Six patients had good results. Nineteen patients improved. Seven patients showed no improvement. In eleven cases, the information was not complete. Thus, following the operation, there was improvement in over 67 per cent. of the patients in this series. Of course, it must be stated that the longest period of observation after operation was only about one and one-half years. It is impossible to foresee whether or not these patients will remain free from pain and capable of carrying on their activities.

In view of the favorable reports from France and the experiences at the Hospital for Joint Diseases, it is believed that the procedure may be of help in many instances. It is possible that, under special circumstances, it may even replace the more extensive procedures. It is not known what is responsible for the return of pain months later, in cases where relief was obtained immediately after the operation. Future experience may throw more light on this problem.

For the present, however, the operation, due to its technical simplicity and the slight amount of adduction, can be used either as an independent procedure, or in conjunction with more extensive operations to relieve or prevent pain in the hip joint.

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SALMONELLA SUIPESTIFER INFECTION OF THE KNEE JOINT

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Salmonella suipestifer, a paratyphoid organism, also known as *Salmonella choleraesuis*, gives rise to three clinical syndromes: (a) acute gastro-enteritis (it may be a cause of epidemics of "food poisoning"), (b) a typhoid-like fever due to bacteriaemia, and (c) a pyogenic infection, in which the organism becomes localized in any one of a number of sites. Cases of this condition have been reported, associated with pyarthrosis, osteomyelitis, purulent meningitis, subdural abscess, pyelonephritis. perinephric abscess, pericarditis, subacute bacterial endocarditis, peritonitis, splenic abscess, empyema of the gall bladder, acute appendicitis (a fatal case), salpingitis, infected uterine myoma, psoas abscess, periproctal abscess, and subcutaneous abscess. The infection will commonly be localized in the lung, where it gives rise to pneumonia.

Because of the absence of gastro-intestinal symptoms in some infections with this organism, and because the reputation of this organism as an abscess producer is not well known, although firmly established, it is thought worth while to report a case of infection of the knee joint with this organism.

PREVIOUS REPORTS

Harvey, in 1937, summarized the findings in seventy-one cases of *Salmonella suipestifer* infections,—fifty from the literature and twenty-one new cases. Twenty per cent. of the patients had involvement of the bones or joints. The sexes were equally affected. The individual joints were involved as follows: knee in four cases, shoulder in six cases, ankle in three cases, and multiple joints in five cases. Harvey mentions two cases with osteomyelitis, involving almost every bone in the body. In the majority of the cases of pyarthrosis and osteomyelitis, articular involvement was the first symptom of note. Only occasionally was a history of trauma to the joint elicited. The involved joint was usually swollen, warm, and tender, and aspiration revealed pus. Osteomyelitis of the adjoining bone was not infrequent. In all the fatal cases there was extensive, multiple involvement of the bones. In no case did mono-articular involvement prove fatal. Five cases of spondylitis, all in men between the ages of seventeen and forty-six, were reported. In ten cases, infection of the costal cartilage was noted,—all in men between the ages of seventeen and thirty-seven years.

Of twenty-eight cases reported by Ravitch and Washington, almost all were in negro children.

Guthrie reported a fatal case of *Salmonella suipestifer* infection in an infant, aged seven months, with pyarthrosis of the right shoulder joint. She stated that, from a survey of the literature, it appears that children are more susceptible than adults to this infection.

Gajzágó and Göttche reported six cases of osteomyelitis due to *Salmonella suipestifer*, all in children under one year of age. They also collected from the literature thirty-four cases of Salmonella infection in children under the age of two, 50 per cent. of whom had osteomyelitis or purulent arthritis.

TABLE I

AGGLUTINATION REACTIONS

Date	Organism	Titer
Sept. 19, 1944	Typhoid H	1 to 320
	Typhoid O	1 to 160
	Brucella melitensis	0
Oct. 4, 1944	Paratyphoid A	1 to 40
	Paratyphoid B	0
	Paratyphoid C	0
	Organism from patient's knee fluid	1 to 320
	Organism from patient's blood	1 to 160

of the left femur. Débridement of the compound wound, manipulation of the fractures, and application of a hip spica were done at a Station Hospital on the day of the accident.

He was admitted to the 17th General Hospital on September 11, 1944. On admission, his temperature was 101.6 degrees; but, except for moderate dehydration, his condition appeared good. Inspection of his compound wound showed no evidence of infection. He was placed on a routine of 25,000 units of penicillin intramuscularly, every three hours; this was continued until October 14. His hematocrit level on September 12 was 25.4 per cent. The blood deficit was made up by repeated transfusions. He continued to have a septic type of temperature, and at times was mildly stuporous. There was daily vomiting, and he had to be given fluids intravenously. Because he gave a history of previous unexplained fever, tests for malaria were done, but no parasites were found. No reason for his fever was discovered.

By September 21, his fever had subsided, the vomiting had stopped, and his condition appeared to be good. Internal fixation of the oblique tibial fracture was done with screws, and the wound was left open. A Steinmann pin was passed through the upper portion of the tibia for treatment of the fractured femur by balanced traction. A toe-to-groin cast was applied.

His condition remained good until the night of September 25, when his fever rose to 102 degrees. He continued to have fever and, on September 28, the compound wound was explored through a window in the cast. The wound was found to be clean and, in spite of the fever, secondary closure was done. On that night, his temperature was 104 degrees, and the following day he complained of pain in the left knee. The cast was removed, and the knee was found to be warm, tender, and distended with fluid. A cloudy fluid was obtained on aspiration. The knee was irrigated with saline solution, and 10,000 units of penicillin was injected.

The patient's temperature continued to rise daily to 102 degrees. Examination of the knee on October 4 showed that it was still distended and tender. Arthrotomy was done through a medial parapatellar incision. The synovial membrane was found to be acutely inflamed. The knee was filled with purulent bloody fluid. No damage to the cartilage was seen. The knee joint was irrigated with saline solution, and the synovial membrane was closed; 10,000 units of penicillin was left in the joint. Because the patient was having so much pain in traction, he was placed in a hip spica. Reduction of the fractured femur had not been obtained with traction. On October 5, an initial dose of 4.0 grams of sulfadiazine was given, followed by 1.0 gram every four hours. On October 15, the dosage was reduced to 1.0 gram every six hours; it was discontinued on October 23.

Penicillin was again injected into the joint on October 6, through a window in the cast. By October 10, the temperature was normal. Inspection of the arthrotomy wound showed it to be clean, and secondary closure was done. There was no recurrence of fever, and the patient's general condition improved satisfactorily.

Because of this serious illness, the patient was not considered able at that time to undergo the operation required for his fractured femur. Accordingly, on November 7, he was evacuated to the Zone of the Interior in a hip spica for further care. Information is not available as to the end results in this case.

Laboratory Studies

Blood for culture was taken on September 19. After six days of incubation, an organism was grown, which was identified as *Salmonella choleraesuis*, variety Kunzendorf. Cultures of fluid aspirated from the knee on September 28, September 30, and October 2 revealed the same organism in each specimen. Subsequent blood cultures (on September 29 and October 4) showed no growth. Stool cultures on October 4 and October 7 showed no pathogenic organisms.

The agglutination reactions noted in the patient's blood are shown in Table I.

The white-blood-cell count varied from 8,150 to 13,600 cells per cubic millimeter during the febrile period of the illness, with an average polymorphonuclear count of 77 per cent. The sedimentation rate on September 24 was 17 millimeters per hour. The hematocrit rose from 25.4 per cent. on September 12 to 40.9

per cent. on October 6; repeated transfusions, totaling five liters, were given during the course of the illness. The blood sulfadiazine level on October 15 was 8.0 milligrams per 100 cubic centimeters.

Questioning of the patient regarding intestinal symptoms revealed that, on September 20, he had had diarrhoea, consisting of two loose stools; by the next day his bowels had returned to normal without treatment.

DISCUSSION

The patient received numerous forms of treatment simultaneously, and it is, therefore, difficult to decide which was effective. Neither sulfadiazine nor penicillin is supposedly effective in Salmonella infections. In this case, a combination of the two drugs, plus local therapy to the joint, was followed by recovery. It is impossible to estimate the role of the repeated transfusions or of the immunity acquired by the patient, in the subsidence of the disease.

The portal of entry is assumed to be the digestive tract. The authors' inability to culture the organism from the stool corresponds with the experience of Guthrie, who stated that the organism is rarely isolated from the faeces. In the case reported by Guthrie, the autopsy showed no intestinal lesions. Similarly, in a case reported by Boycott and McNee, the autopsy disclosed no significant intestinal lesions.

The marked trauma in the patient reported here may have favored localization of the infection to an adjacent joint. The debilitated condition of the patient may have contributed to the severity of the infection. Goulder, Kingsland, and Janeway point out that, when infection with *Salmonella suipestifer* occurs in epidemic form as acute food poisoning, the mortality is low; but when it occurs in endemic form, it often complicates some debilitating disease and has a considerable mortality.

Age is very important in the prognosis of bacteriaemia with this organism, according to Harvey. The mortality in patients less than twenty-five years of age was 19 per cent. in his series, while among patients over twenty-five years of age it rose to 58 per cent.

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SALMONELLA SUIPESTIFER PYARTHROSIS OF THE KNEE JOINT

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Infection with *Salmonella suipestifer* is unusual in man. It is not listed in Barnes's grouping [2] of the twenty-four Salmonella types found most frequently in human infections; this grouping was based upon data compiled from the National Salmonella Center, Washington, D. C.

Although paratyphoid bacilli, types A, B, and C, are generally considered the causative agents in "paratyphoid fever", almost 180 Salmonella types have been identified by serological and bacteriological means. Of these, approximately seventy-five have been recovered from human infections, and the balance from various bird and animal sources. The term salmonellosis, which includes the name of the specific etiological organism, is suggested by Barnes as a more accurate designation for the members of this group.

Bone infection results from extension of the enteric infection by way of the blood stream. The original infection may appear as (1) enteric fever, in which there is early extension of the organism into the blood stream, with such symptoms as fever, malaise, insomnia, and headache, appearing from seven to fourteen days after ingestion of the organism; (2) acute gastro-enteritis, in which a prolonged infection of the intestinal mucosa leads to late ulceration and resultant late bacteriaemia; or (3) a carrier infection, without previous gastro-intestinal symptoms. Because the majority of the salmonelloses are primarily of animal origin (occurring in domestic and wild birds, horsemeat, pork and pork products, duck, pigeon, and goose eggs, rats and mice, house flies and mosquitoes, wood ticks, and many others), human sources of infection have been largely ignored. However, Rubenstein, Feemster, and Smith isolated various Salmonella types from humans who remained infectious for periods up to six months, and even for one year after an enteric infection. Permanent human carriers are well-known sources, and are less apt to be overlooked than are persistent convalescent carriers and unrecognized cases of subclinical infection. Thus salmonellosis may spread from case to case without animal propagation.

The epidemiological and clinical implications of Salmonella infections have resulted in many contradictory reports. Because of the mild nature of some paratyphoid cases and their uncharacteristic clinical picture, which may simulate any of several common symptom-complexes, it is believed by some that these infections are inconsequential, except in infants and in the aged. Actually, persons in all age groups are susceptible to Salmonella infection, but the majority of cases do occur during the first decade of life. In Rubenstein's cases of *Salmonella typhimurium*, 39 per cent. of the patients were under ten years of age. An unusual case of *Salmonella montevideo* pyarthrosis of the knee, to be reported by Dr. Theodore H. Vinke, was also in a child.

Salmonella suipestifer or hog-cholera bacillus is usually found in association with the virus of hog cholera, but has also been isolated from cattle, sheep, and rodents, as well as from tapioca pudding, ice cream, milk, and crab meat. Human infections with *Salmonella suipestifer* have been reported from all parts of the world since it was recognized by Longcope in 1902. They frequently occur in epidemics, and are usually dietary in origin [13].

Salmonella suipestifer is a gram-negative, motile bacillus, belonging to Group C of the Kauffmann-White classification of Salmonella [6]. Jager and Lamb state that it is recognized "by its selective fermentation reactions and by agglutinations with specific antiserums". "The term '*Salmonella suipestifer*' includes several organisms that have both the somatic antigens VI and VII but differ slightly in their flagellar antigenic components and in their selective fermentation reactions." The organism is bacteriologically closely similar to Salmonella of the Oranienburg type.

Infections with *Salmonella suipestifer* in the human usually run a short but stormy course, and subside spontaneously. Numerous cases of bacteriaemia have been reported, but positive blood cultures are exceedingly difficult to obtain.

Hunter, Andresen, and Hutchinson state that the most frequent complications noted are infections of the bones and joints, purulent meningitis, endocarditis, urinary-tract infections, and secondary infections of surgical wounds. Abscess formations in other parts of the body are rare, but do occur.

Weaver and Sherwood, in 1935, reported a case of *Salmonella suipestifer* pyarthrosis of the knee joint in a nine-month-old girl. The patient had a septic course, characterized by moderate effusion and a local area of induration over the medial femoral condyle. There was roentgenographic evidence of a ragged line at the lower femoral epiphysis with spurring; elevation of the periosteum was present. At operation the periosteum was found to be ruptured just above the medial aspect of the lower femoral epiphysis; and thick yellow pus overlay the necrotic bone. The wound was drained and packed with petrolatum gauze; and the limb was immobilized in plaster, with good resulting function. Weaver and Sherwood believed that pyarthrosis due to *Salmonella suipestifer* occurred only in infants; the primary focus was in the epiphyseal plate, with extension toward the joint.

Harvey, in a comprehensive survey of fifty reported cases of *Salmonella suipestifer* infection in human beings, with the addition of twenty-one cases of his own, divided sporadic infections into two major clinical groups: The first and larger group included typhoid-like infections, characterized by bacteriaemia without localizing signs. There was usually a sudden onset, chill and fever, anorexia, vomiting, headache, rapid pulse, leukopenia, and mild bronchitis in older patients. In the second group were found infections with bacteriaemia and localization, most frequently in the pulmonary area, with resultant bronchopneumonia, lobar pneumonia, pleurisy with effusion, or empyema. Other sites of involvement were the bones and joints (in fifteen of the seventy-one cases surveyed), surgical wounds, endocardium, urinary tract, and meninges. With the localization there was suppuration and a white blood count of from 16,000 to 28,000.

Harvey noted in his cases that objective evidence of articular involvement was delayed from a few days to two months, although in the interim the patient usually complained of general malaise and had difficulty in using the affected extremity. A history of trauma was occasionally elicited. The patient usually had a remittent fever, but was sometimes afebrile. Examination revealed a warm, swollen, tender joint with erythematous skin and pain on active and passive motion. Effusion was almost always present. Greenish purulent material was obtained on aspiration; culture yielded pure *Salmonella suipestifer*. Osteomyelitis of adjacent bones was frequently found. Roentgenographic findings were often normal in the early stages, but later such changes as periosteal thickening, rarefaction, and erosion of the adjoining bone were seen.

Harvey listed four cases involving the sacro-iliac joint, ten with infection of the costal cartilage, two of the sternoclavicular joint, three of the hip joint, two of the knee joint, and one of the symphysis pubis,—a definite predilection for the amphiarthroidal type of joint. Except for one ten-year-old girl, all of the patients were men, ranging in age from seventeen to thirty-seven years. Treatment by repeated aspiration or open drainage of the joint, and traction or immobilization as indicated, usually resulted in rapid fall of the temperature to normal, gradual subsiding of the swelling, and free joint motion in from three to six weeks, with resultant complete function.

Ssokoloff mentions thirty cases of surgical complications, including five cases of spondylitis; his patients were men, ranging from seventeen to forty-six years of age.

The following case of *Salmonella suipestifer* pyarthrosis of the knee joint is of unusual interest, because of a pre-existing osteochondritis dissecans of the femoral intercondylar notch, which may well have been a factor in the localization of the infection.

CASE REPORT

E. T. (Cincinnati General Hospital No. 214428) was a single negro male, thirty-eight years old. He was admitted June 3, 1946, with a chief complaint of pain in his left knee (Fig. 1-A). Ten days before admission, he tripped and struck his left knee on the sidewalk; this was followed by pain of several hours' duration. After the pain had disappeared, he was able to return to work. The day before admission he awoke with sharp pain in his left knee, despite which he was able to get around. The knee was quite warm, but not swollen. That night his knee became swollen and warmer; he felt feverish; and he was unable to bear weight on the knee.

There was no history of familial disease or of tuberculous contacts. The past history revealed that, eleven years before, his left knee had been struck by a baseball bat. The injury produced pain and swelling which were treated by limited weight-bearing for four months. Following this episode the knee always seemed larger than the right one, and the patient had intermittent periods of pain and swelling after minor traumata. Two years before admission he fell, while working at an airplane plant, and injured his knee once more; thereafter, pain and discomfort became more frequent and more intense. He had been given a medical discharge from the Army eight months before onset of his present difficulty, because of recurrent effusions, requiring aspiration, and limited function of his left knee after a fall from a motorcycle. His service had been largely in the Midwest, and he had not left the United States. He denied any venereal disease or urethral discharge. There had been no ingestion of uncooked meats or unpasteurized milk, and no dietary indiscretions.

On admission, the patient's temperature was 101.6 degrees, pulse 68 and respirations 22 per minute. The blood pressure was 130 systolic and 76 diastolic. Physical examination showed a well-developed, well-nourished negro male in moderate distress, lying on his right side. Positive findings were limited to the left knee, which was swollen, hot, and exquisitely tender over the entire joint area; moderate effusion was present. The knee was held in 175 degrees of extension; attempted flexion was painful and was limited by muscle spasm.

The blood findings on admission were as follows:

Red blood cells	5,750,000
Hemoglobin	12 grams per 100 cubic centimeters
White blood cells	8,450
Polymorphonuclear neutrophils	65 per cent.
Lymphocytes	33 per cent.
Monocytes	2 per cent.

The urine contained a trace of albumin and from ten to twenty white blood cells per high-power field. Urethral and prostatic smears were negative for gram-negative intracellular diplococci. The blood Kahn reaction was negative. The blood urea nitrogen was 14 milligrams per 100 cubic centimeters. An electrocardiogram revealed nothing abnormal.

Aspiration of the knee-joint fluid was performed in the receiving ward, and 65 cubic centimeters of amber cloudy fluid, filled with pus cells, was sent to the laboratory for culture and analysis.

Roentgenograms of the chest were negative. Roentgenograms of the left knee revealed osteochondritis dissecans of the intercondylar notch of the femur, and swelling of the joint capsule.

Sulfadiazine, an initial dose of two grams and then one gram every four hours, was instituted on the day of admission, following a presumptive diagnosis of gonococcal arthritis; but the temperature rose to 103.6 degrees, despite maintenance of adequate blood levels. Penicillin, 20,000 units intramuscularly every three hours, was, therefore, added the following day. On the second day of the patient's stay in the Hospital, 65 cubic centimeters of a yellow, turbid, viscid fluid was aspirated from the joint. Microscopic analysis disclosed 17,500 white blood cells with 88 per cent. polymorphonuclears, and 4,125 milligrams of protein per 100 cubic centimeters. Direct smears were negative, including acid-fast stains. The fluid was sent to the central laboratory for culture. The dosage of penicillin was increased to 25,000 units every two hours, but the knee remained hot, tender, and swollen, and the high fever continued.

Blood cultures were taken on the patient's second and fourth days in the Hospital; they were reported as negative.

Daily aspirations of the joint fluid were performed; the purulent and high-protein character of the fluid remained essentially the same. On the fourth day in the Hospital, the first culture of the knee-joint fluid was reported to contain an unidentified gram-negative bacillus. Further laboratory studies were instituted, including a blood Widal test for typhoid and paratyphoid, A and B, brucellar agglutinations, and a complement-fixation test of the blood for gonococcus. All of these tests were negative. On the tenth hospital day the organism, found in the aspirated fluid on admission, was identified positively by fermentation and serological reactions as *Salmonella suipestifer* (Kunzendorf variety). This was confirmed by reports of positive cultures in each of the nine daily aspirations of the knee-joint fluid, performed subsequently. Stool cultures were negative for pathogenic organisms. In view of the finding of a gram-negative bacillus, and the lack of response to previous therapy, the sulfadiazine and penicillin were discontinued, and streptomycin therapy was begun (on the seventh hospital day).

FIG. 1-A

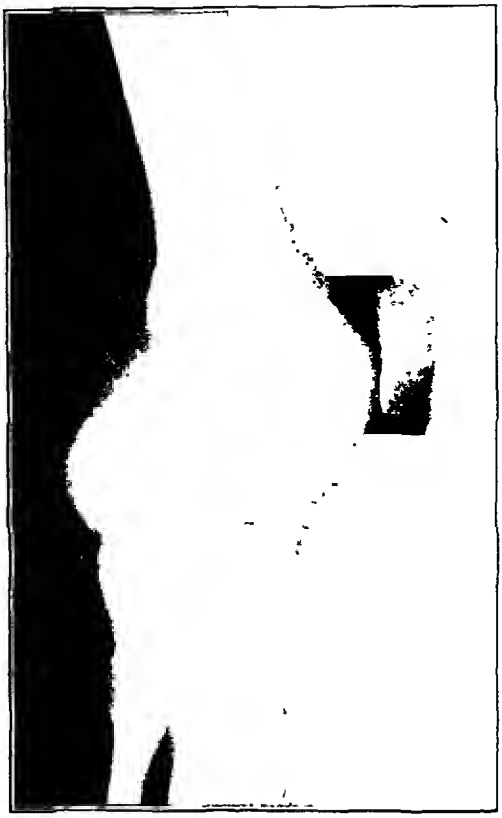

FIG. 1-B

Note the lesion of osteochondritis dissecans in the posteromedial portion of the medial femoral condyle in both roentgenograms. There is also an appreciable widening of the interarticular space, and minimum hypertrophic lipping of the medial tibial tuberosity in the anteroposterior view.

The intramuscular administration of 125 milligrams of streptomycin in 3 cubic centimeters of saline every three hours resulted in a rapid fall in temperature, and in negative joint and blood cultures. However, the streptomycin had to be discontinued after nine days, because of repeated sterile abscesses at the sites of injection.* Two days later the joint fluid again gave a positive culture for *Salmonella suipestifer*, and additional streptomycin was given by the intravenous route; this form of administration, too, had to be discontinued, because of a severe febrile reaction and local thrombophlebitis. The temperature dropped to normal by lysis on the twenty-sixth hospital day, and remained normal thereafter (Fig. 1-B).

The fluid in the knee again required aspiration on July 7 (the thirty-fourth hospital day), at which time cultures for *Salmonella suipestifer* were still negative; however, there were 7,800 white blood cells per cubic millimeter. Blood agglutinations, taken at this time for paratyphoid B, were positive up to dilutions of 1 to 320. The knee improved progressively, so that, on the forty-second hospital day, it was no longer swollen or tender. Motion was still restricted, however, from 180 degrees of extension to 105 degrees of flexion. There was still some synovial thickening, but no effusion. Physiotherapy was begun cautiously, and resulted in an increased range of motion. The patient was discharged from the Hospital on July 26, the fifty-second hospital day, on crutches without weight-bearing.

He failed to appear for his physiotherapy appointments, and when next seen in the Orthopaedic Clinic, on August 2, two months after his original admission, there had been some regression in joint motion, the range then being from 180 to 130 degrees. The patient had discarded his crutches of his own accord. When seen two weeks later, there was some residual thickening of the left knee, which was three-quarters of an inch larger in circumference than the right knee, and the range of motion was from 175 to 100 degrees. Slight tenderness was noted on the anteromedial aspect of the joint. A culture, secured by saline lavage of the joint, was reported as negative. The patient was last seen on August 30, at which time there was no swelling or tenderness, no synovial thickening, and no instability. He had a range of motion from 180 to 90 degrees, and he was able to resume his occupation as a tire worker.

* A report on streptomycin, to be published by the Department of Medicine, will include further details of the streptomycin therapy and its complications.

COMMENT

The presence of a degenerative joint lesion, osteochondritis dissecans, which had been aggravated by repeated traumata, may have predisposed the joint to localization of the infection. However, it apparently did not influence the course of the infection, since complete recovery occurred in three months from the time of onset, without extension of the suppurative process into the adjoining bones. This might have been expected from the loss of the normal cartilaginous barrier in the region of the osteochondritic defect. The defect showed no roentgenographic change during the course of the infection.

Only a few cases of typhoid and Salmonella infections have been treated by streptomycin. Results were reported as generally unsatisfactory [7]. In this case, clinical improvement (fall of temperature and pulse to nearly normal and decreased swelling and pain in the knee) was manifest three days after streptomycin therapy was begun. The positive joint cultures became negative and remained so, when sufficient streptomycin had been given.

Although the infection resolved completely, and the immediate functional result was excellent, it is to be expected that the degenerative changes of osteochondritis dissecans, previously present, will result in more joint disturbance at a later date. An arthrotomy may be required, but this will be delayed until it is deemed safe to open the joint.

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FRACTURE OF THE FEMORAL SHAFT COMPLICATED BY HIP DISLOCATION

A Method of Treatment

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Traumatic dislocation of the hip is a relatively rare injury, comprising about 2 to 5 per cent. of all dislocations. Dislocation of the femoral head, complicated by a fracture of the femoral shaft, is an extremely rare lesion which always presents a problem of treatment. Such a case is reported here because of the method of treatment which, as far as the authors are aware, has not been described previously.

John Royal Moore classified fracture-dislocation of the hip as follows:

1. "Central dislocation of the femoral head.

2. "Posterior dislocation of the femoral head accompanied by fracture of the acetabular rim.

3. "Posterior dislocation of the acetabulum accompanied by fracture of the femoral head."

To this classification, we must add two types less frequently seen:

4. Dislocation of the hip with fracture of the neck of the femur, as described and treated by Hart and Watson-Jones with Whitman reconstruction operations.

5. Dislocation of the hip, accompanied by a fracture of the shaft of the femur.

The last type is found less frequently than the first four, and it is in this last classification that the case reported here belongs. In reviewing the literature, we find only scanty mention of this type of injury, although we feel sure that many of these injuries occur in this automotive age and go unreported.

In 1934, Henry and Bayumi reported one case of dislocation of the hip with fracture of the shaft of the femur among 9,945 cases of fractures and dislocations, treated over an eight-year period in a Cairo hospital, or approximately one case in 10,000. They reviewed the literature and found fifteen other cases, most of which had occurred in the nineteenth century; the first one was reported by Sir Ashley Cooper, in 1823. Over a period of thirty-one years at Henry Ford Hospital, four cases have been seen in a total of 496,700 patients. This would be about one case in 125,000.

King and Richards, in their very complete article on fracture-dislocations of the hip joint, mentioned this condition as one of the five indications for open reduction. They stated that they had treated one patient with dislocation of the hip and fracture of the femoral shaft, and had observed two others. Watson-Jones referred to this type of fracture-dislocation of the hip by saying: "Sixteen cases have been recorded . . ." These were probably the sixteen cases mentioned by Henry and Bayumi in 1934. Watson-Jones advocates open reduction, if manipulative reduction fails. Key and Conwell also discussed this as a rare type of injury, and suggested the same treatment as that advocated by Watson-Jones. Hammond commented: "Dislocations complicated by fractures of the shaft of the femur often necessitate open reduction".

Of the authors' four cases, open reduction of the dislocation of the hip was required in three. We were able to reduce the dislocation in the case described here by closed reduction with the method mentioned, in spite of the patient's strong musculature.

CASE REPORT

M. O. (Case No. 471057) was a white male, thirty-five years old, who, while welding at the Ford Motor Company on March 25, 1946, was struck from behind, when kneeling, by a large girder which had slipped

from an overhead crane. This girder struck the patient over the posterolateral aspect of the left thigh, knocking him to the ground. The patient stated that he felt a crumbling of bones in his left lower extremity, had severe pain, and was unable to get up. One hour later, when the patient was examined at the Hospital, he was in mild surgical shock and had a dirty six-inch transverse laceration of the supracondylar area of the femur, a large hematoma over the left gluteal region, and a gross deformity with angulation of the upper third of the left thigh. There was inability to extend the proximal fragment and, therefore, a marked bowing at the juncture of the middle and upper thirds of the left femur. Roentgenograms disclosed an oblique fracture of the upper third of the left femur, and a complete posterior dislocation of the hip joint (Fig. 1).

The patient was treated for his mild shock with fresh whole blood; then the wound of the supracondylar area was irrigated, debrided, and closed under general anaesthesia. Following this, an unsuccessful attempt at closed reduction of the dislocated hip was made with the Bigelow and Allis procedure. Thereafter, a reduction-retention apparatus with threaded pins was used, with the pins placed approximately four inches apart into the lateral aspect of the trochanter of the left femur (Fig. 2). Another attempt at closed reduction was made, the pins being used in an effort to control the proximal fragment; but, because of this patient's musculature and marked muscle spasm, this attempt also was unsuccessful. A Kirschner wire was placed through the area of the tibial tubercle; the patient was sent to the ward and placed in traction, with twenty-five pounds of weight on the Kirschner wire and another twenty-five pounds of weight on the reduction apparatus.

On March 28, three days after the injury, another unsuccessful attempt at closed reduction was made; the reduction apparatus was used to control the proximal fragment. Following this, a two-foot length of gas pipe was threaded over the crossbar of the reduction apparatus (Fig. 3), thus paralleling the distal fragment and being attached through the apparatus to the proximal fragment. With the gas-pipe lever, a successful reduction was carried out, by means of the Bigelow manoeuvre. The patient was then returned to the ward, where he was placed in skeletal traction. Roentgenograms, taken the next day, showed the head of the femur to be in the acetabulum and the fracture to be in almost anatomical position and excellent alignment (Fig. 4).

On June 29, approximately three months later, the patient was put in a plaster hip spica. This was maintained until the first week in September 1946, when it was found, after testing the patient clinically and taking roentgenograms, that he had non-union at the fracture site and that the proximal fragment of the femur cast a shadow of increased density (Fig. 5-A). It was thought at that time that the increased density of the proximal fragment was due to massive stripping of the periosteum at the time of the original injury, since the proximal fragment had been considerably displaced because of the dislocation of the hip. The patient's skin

Fig. 1

Fig. 2

Fig. 1: March 25, 1946. Roentgenogram, taken the day of the accident, shows posterior dislocation of hip and fracture of shaft of femur.

Fig. 2: March 29, 1946. Shows reduction-retention apparatus in place, with threaded pins extending into trochanteric region of femur. Dislocation of hip has been reduced.

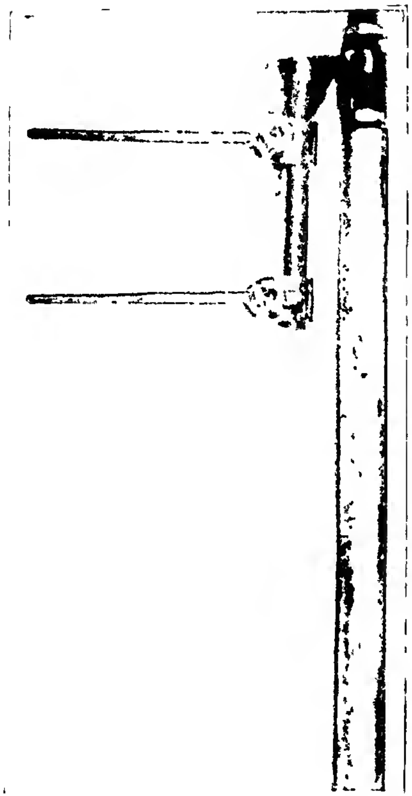

FIG. 3

FIG. 4

FIG. 5-A

FIG. 5-B

Fig. 3: Photograph of threaded-pin apparatus, with two-foot piece of gas pipe attached.
Fig. 4: April 11, 1946. Pins of the reduction apparatus have been removed and the patient has been placed in skeletal traction.
Fig. 5-A: September 9, 1946. Roentgenogram, taken six months after reduction, shows sclerosis of proximal fragment of femur and non-union of fracture.
Fig. 5-B: December 31, 1946. Twelve weeks after open reduction and tibial onlay bone graft. There is no evidence of aseptic necrosis of the head of the femur.

was prepared for surgery during the last two weeks of September. On September 30, 1946, an open reductior was performed; and a Vitallium plate and massive onlay bone graft from the tibia were placed across th fracture site. The postoperative course was uneventful, and the patient remained in the hip spica until December 31, when it was found by clinical and roentgenographic examination (Fig. 5-B) that he had solid bony union. Since that date he has received physiotherapy to the hip, knee, and ankle, and has been walking with a double upright, non-weight-bearing brace.

At present the patient has considerable limitation of flexion of the knee; he can flex the hip to 90 degrees, although there is still rather marked limitation of internal and external rotation of the hip joint. To date there has been no evidence of aseptic necrosis of the head of the femur.

CONCLUSIONS

Dislocation of the hip, complicated by a fracture of the shaft of the femur, is an exceedingly rare condition and presents a most difficult problem in reduction. It is a well-known fact that this type of injury occurs in young and middle-aged adults most frequently, and is caused by only the most violent forms of trauma. For this reason, it is usually seen in a very muscular type of patient, which makes closed reduction even more difficult.

The problem in reduction arises from the fact that the lever arm, the femur, is not intact and one has no control over the proximal fragment. The authors were able to restore the lever arm by means of the gas-pipe extension on the pin-fixation apparatus, and thus were successful in the reduction.

The authors feel that non-union developed because of the excessive stripping of the periosteum from the proximal fragment, caused by the marked displacement resulting from the dislocation of the hip. The increase in density of the proximal portion of the shaft of the femur, probably due to the damage to the blood supply secondary to the periosteal stripping, is shown in Figure 5-A.

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THE TREATMENT OF DROPPED SHOULDER

A New Operative Technique

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Paralysis of all shoulder muscles is apt to affect seriously the function of the shoulder girdle. The characteristic features of this condition are:

1. Distal and ventral sliding of the scapula.
2. Winging of the scapula (scapula alata).
3. Abolished function of the posterior cervical muscles, causing a forward inclination of the head.
4. The weight of the arm, no longer subject to muscle control, draws the head to the paralyzed side.

The object of therapy is twofold: (1) fixation of the scapula to the thorax, and (2) correction of the pathological posture of the head.

Plastic operations, as devised by Henry, Whitman, Dickson, and Dorling, consist essentially in the construction of fascial slings, leading from the scapula to the muscles and the spinous processes of various thoracic vertebrae. These methods are chiefly used in cases of unopposed action of the serratus. Hence, they are dealing merely with one of the pathological components in question. Dickson described a method for lifting a drooping shoulder after paralysis by the use of two fascial slings, leading separately from the spine of the scapula to the cervical muscles and the spinous process of the first thoracic vertebra. Nothing, however, is known of the late end results following this method.

Every operation which consists in transplantation of fascia is likely to yield satisfactory results, if the transplanted fascia is actually converted into solid scar tissue. It is, however, still doubtful if these strong bands are able to carry the weight of the arm permanently, without the assistance of the muscles.

In two particularly difficult cases of paralysis of the shoulder after anterior poliomyelitis, our procedure was totally different. The method employed consisted essentially in fixing the scapula to one of the ribs. Three different methods were used, as one of the patients had to be operated upon twice.

CASE REPORTS

Case 1. The patient, a boy fourteen years of age, was admitted to the Hospital on March 27, 1942. Five days previously he had been taken ill with acute poliomyelitis. During the first two days of his hospital stay, paralysis spread to all four extremities and to the trunk. On the third day, respiration became difficult; and he was placed in the "iron lung", where he was left for six days. At the end of that time his condition had improved so much that normal respiration took place. The paralysis of the lower extremities and hands subsided slowly. When he was discharged, in June 1942, he still presented extensive paralysis of both shoulders,—namely, in the deltoid, supraspinatus, infraspinatus, and trapezius muscles. On the right, there was still a trace of function in the superior part of the trapezius, the posterior cervical muscles, and the serratus anterior.

In spite of intensive exercise and fixation of both shoulders, a high thoracic scoliosis developed, with its convexity to the right. The patient found it particularly embarrassing that his chin was lying on his chest and that he was unable to raise his head. The right shoulder dropped more and more. In order to look around, the patient had to hold his lumbar spine in exaggerated lordosis, which interfered seriously with normal walking. He suffered, moreover, from severe headaches when walking, probably caused by the abnormal posture of his head (Figs. 1-C and 1-D).

Our first object was to fix the drooping shoulder girdle and then to replace the elevators of the head by fascial transplantation.

First Operation (May 25, 1943)

Under general anaesthesia, the lower edge of the right scapula and the fifth and sixth ribs were exposed subperiosteally. The fifth rib was resected to a length of six centimeters. In the distal end of the scapula (angulus inferior) two holes were bored, and through each of them a length of wire was passed. The distal end of the scapula was slipped through the defect, created by the resection of the fifth rib, and was placed behind the sixth rib, to which it was fixed by the two wire loops (Fig. 1-A). The wound was closed and the arm was fixed to the chest by a Velpeau bandage.

Roentgenographic follow-up after ten days showed that the wires had become loose, so we assumed that the fixation of the scapula would be inadequate and decided to operate again.

Second Operation (June 13, 1943)

Under general anaesthesia, the distal end of the scapula and the sixth rib were exposed. The wire had cut through the scapula on one side, while on the other it had become loose. It did not seem advisable to try the same method of fixation again, so we proceeded as follows: The distal end of the scapula was split along its long axis to a length of two centimeters. The two jaws were placed on the sixth rib, the scapula, as it were, riding on the rib (Fig. 1-B). The wound was closed and the arm was placed in a Velpeau bandage for five weeks. After the bandage had been removed, the scapula proved to be firmly attached to the rib.

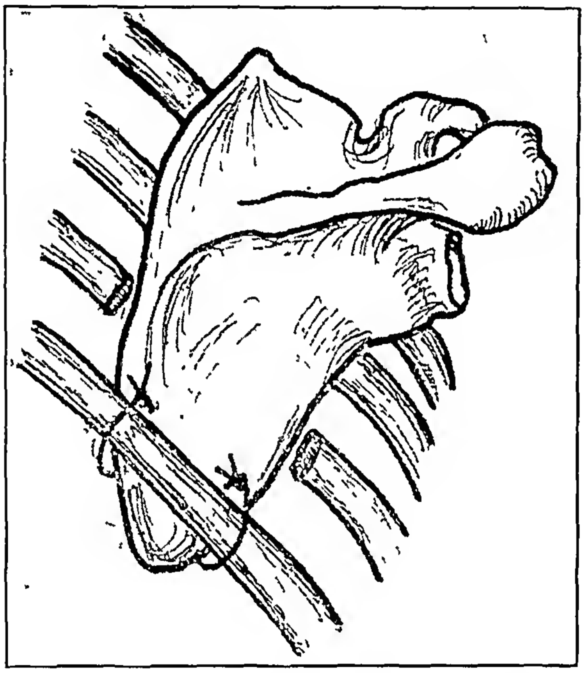

Fig. 1-A

Fig 1-A: Shows resection of fifth rib and attachment of scapula to sixth rib by wire loops.

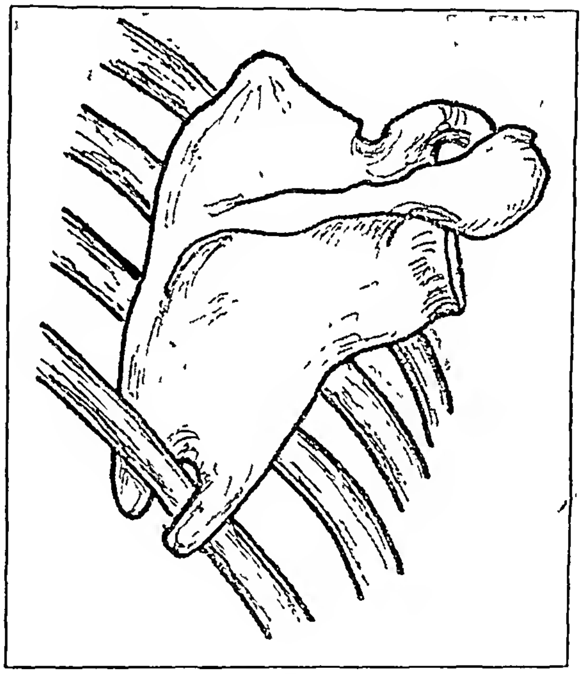

Fig. 1-B

Fig 1-B: In the second operation, the scapula was split so that it rests on the sixth rib

Fig. 1-C Fig. 1-D

Case 1. Photographs taken before operation.

Fig. 1-E Fig. 1-F

Photographs taken in 1945.

Follow-up Examination (October 1945)

The shoulders were at the same level on both sides. The head was carried free and straight. Only the upper portion of the trapezius on each side was rated fair and participated in the raising of the head. Otherwise, there was no change in the muscle state (Figs. 1-E and 1-F). The right arm could be abducted passively to 90 degrees; this was accompanied by an upward movement of the clavicle. This fact is particularly important as it indicates that, in spite of extensive fixation of the scapula to the rib, the "pseudo-articulation" between the scapula and the rib allows a certain amount of movement.

For the past year the boy, now eighteen years old, has been working in a glass-cutting and optical workshop. The headaches, which had been a great nuisance prior to the operation, have disappeared. Abduction of the arms is still impossible, but he is able to look after himself without any help.

Case 2. The patient, a man twenty years of age, was admitted to the Hospital on June 27, 1942. Three days before, acute poliomyelitis had developed. On admission, he presented paralysis of both arms and paresis of both legs, as well as disturbed deglutition. When he was discharged, in September 1942, he still presented paralysis of the left deltoid, the upper part of the trapezius, and all the shoulder muscles on the right.

A high thoracic scoliosis developed, with its convexity to the right. The right shoulder was lower than the left one, and the vertebral edge of the scapula winged distinctly (scapula alata). The chin was resting on the chest and the head was inclined toward the right side. Lifting of the head was possible only by bending the trunk backward and relaxing, as far as possible, the sternomastoid muscles.

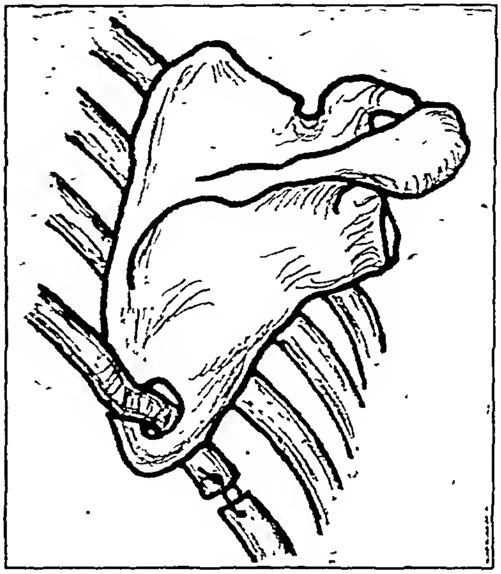

Fig. 2-A

Operative procedure carried out in Case 2. The rib has been passed through a hole bored in the scapula.

Fig. 2-B

Fig. 2-C

Roentgenograms show fixation of scapula to rib.

In view of our experience in the preceding case, another method of fixation was tried.

Operation (May 8, 1944)

Under local anaesthesia, the lower part of the right scapula and the sixth rib were exposed subperiosteally. The rib was cut at the level of the posterior axillary fold. The dorsal portion was grasped by pliers, crushed, and bent upward. Into the lower angle of the scapula, a hole was bored of a diameter of approximately two centimeters, through which the rib was passed in such a way that the vertebral edge of the scapula was covered by the rib dorsally. The two ends of the rib were approximated and fixed loosely to each other by bone suture (Fig. 2-A). The intercostal nerves were blocked by a 1 per cent. novocain solution. A Velpeau cast was applied, and worn for four weeks.

When the cast was removed, it was found that bone healing had taken place at the site of resection, and that the scapula was immovably fixed to the rib (Figs. 2-B and 2-C).

Follow-up Examination (November 1945)

The shoulders were at the same level on both sides, and the head was carried free without any effort. Active elevation of the head was performed by the posterior cervical muscles with fair strength. The function of these muscles before the operation could not be traced. The right scapula was absolutely immovably fixed to the rib. Although there was still paralysis of the deltoid muscle, the right arm could be moved more freely than prior to the operation. After his operation the patient, who lived in an agricultural communal settlement, was again fit for physical work.

COMMENT

An attempt was made to improve conditions of extensive paralysis of the shoulder muscles, by three different operations.

The first, consisting in fixation of the scapula by wire, proved a failure. Whether this was due to an inadequate technique or to insufficient immobilization after the operation is difficult to decide. Of the three methods tried, this was the least satisfactory, since foreign material introduced into the tissues in the neighborhood of the pleura will always give rise to complications.

The second method, consisting in splitting the scapula and making it "ride" on the rib, has the advantage that, after perfect fixation has been established and the position of the scapula has been rectified, a certain amount of movement is still possible between the scapula and the chest wall. It will probably have to be decided for each case individually, whether or not resection of the fifth rib is really necessary in order to attach the scapula alata to the chest. Of special advantage is the "pseudarthrosis" between scapula and thorax, in view of the fact that the mobility of the shoulder girdle depends upon the mobility of all the individual parts of this complex. This method of fixation of the scapula might possibly be used advantageously as a preliminary act for plastic operations on the paralyzed deltoid muscle. After the transplantation, part of the initial success is often lost, owing to the inability of the transplanted muscles to carry the weight of the arm and to restore its function. By this second operation, the first object is achieved and the transplanted muscle may now serve exclusively to improve function.

The third method, by which the rib is passed through the scapula, effects the most secure and solid union. It has, however, the disadvantage that movement between the scapula and the thorax is completely and permanently destroyed. This type of fixation should be confined to cases in which muscle transplantation is impossible, owing to lack of material.

The author's reconstruction included a second stage, consisting in correction of the abnormal posture of the head. In both cases, however, it could have been omitted, since in each the head could be moved and held straight without effort after the operation, although in one case the upper portions of the trapezius muscles were only fair and in the second case the posterior cervical muscles were only fair. This would suggest that the main reason for the abnormal posture of the head is a shift of balance within the shoulder girdle; and, as soon as this has been rectified, the head can be balanced normally on the trunk without considerable active effort.

NOTE: The author wishes to express his sincere thanks to Dr. K. Friedman, the thoracic surgeon of the Beilinson Hospital, for his active cooperation in the performance of the operations.

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A DEPTH GAUGE FOR BONE SURGERY

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A simple depth gauge has been designed to ensure, easily and quickly, the proper length of screws in bone surgery. The instrument of this type most often seen in general use consists of a slim steel bar with a hook or right angle on the distal end. Upon this rod is mounted a sliding metal collar with a set screw to fix it firmly to the rod at the desired place. This device has certain drawbacks, the most important of which is that the set screw must be screwed in firmly or not at all. When the instrument has been passed through the screw hole, the bent end engaged in the opposite cortex, and the sliding collar pushed against the proximal cortex, the set screw must be engaged firmly. This manoeuvre often prevents the disengagement of the instrument and its withdrawal from the drill hole. It is necessary then to loosen the set screw, and an error is introduced when the sliding collar backs away from the bone.

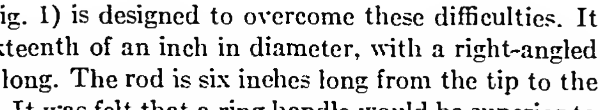

FIG. 1

The instrument described here (Fig. 1) is designed to overcome these difficulties. It consists of a stainless-steel rod, one-sixteenth of an inch in diameter, with a right-angled end (*A*), two thirty-seconds of an inch long. The rod is six inches long from the tip to the proximal end, which is bent into a ring. It was felt that a ring handle would be superior to increasing the caliber of the rod at the proximal end (*D*), and thus increasing the likelihood of bending the thin distal segment when the gauge was in use.

Upon this rod is a sliding spring of stainless steel (*C*). This spring is so bent that it can be moved toward the distal end of the rod by pressure on the arm closer to the ring, but it will not slide back toward the handle unless both members are squeezed together.

To use the instrument, the distal end is passed through the drill hole until the right angle can be engaged on the opposite cortex. The spring is then slid up against the bone. It remains there by its own tension. By a slight twisting motion, the hook can be disengaged without the spring backing up more than a tiny fraction of an inch. The proper length of screw is then determined by direct comparison.

OLECRANON FRACTURES

A Method of Wiring

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During the past seven years at the United States Marine Hospital, a method of wiring the fragments in fracture of the olecranon has been devised, in which a 22-gauge steel wire has been used for fixation and immobilization of the approximated bone fragments. This procedure has permitted motion in two to three weeks, without danger of separation of the fragments at the fracture site; possible buckling of the bone fragments, anteriorly, posteriorly, or laterally; or axial rotation.

Open reduction is indicated when there has been a fracture of the olecranon with separation or angulation of the fragments, producing a disturbance of the concavity of the semilunar notch. The procedure to be described has also been used in conjunction with the preliminary fixation of fractures of the olecranon, when they have been associated with fractures or dislocations of the radius or with fractures of the condyles of the humerus.

A posterior elliptical incision is made in the region of the elbow. The olecranon is exposed by blunt dissection. The anconeus and supinator on the lateral aspect of the

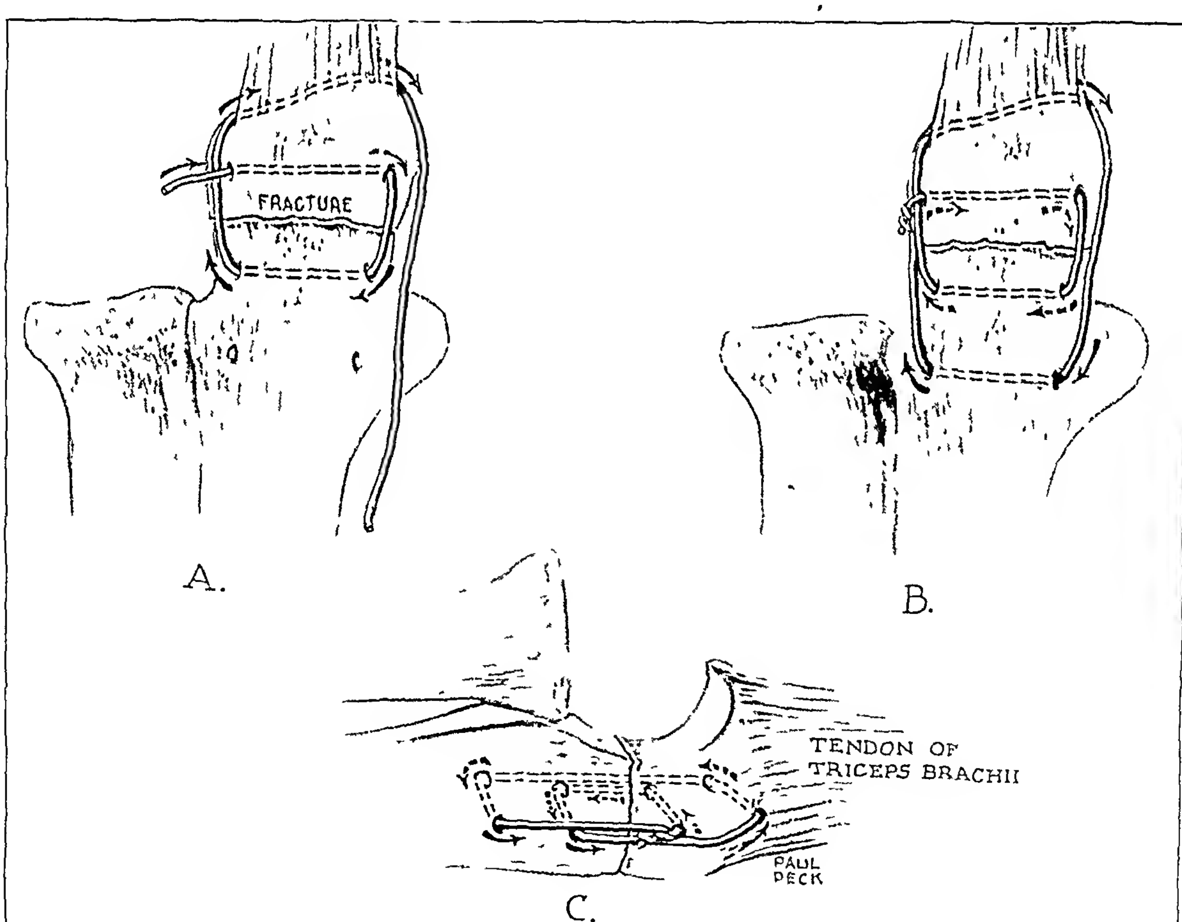

Fig. 1

Wiring of olecranon. *A:* Passage of 22-gauge stainless-steel wire through drill holes near fracture site. *B:* Twisting and fixation of wire loop. *C:* Lateral view, showing position of drill holes and direction in which wire is threaded.

olecranon are dissected from the bone, as is the flexor digitorum profundus, for a distance of approximately one inch distal to the site of fracture. By a No. 1 drill, two holes are placed through the bone transversely (slightly eccentric to the mid-shaft) one-quarter of an inch above and below the fracture line. In cases of comminution, the main fragments are drilled. Another drill hole is placed transversely, a thumb's breadth below and parallel with the primary drill hole on the distal fragment.

Beginning on the radial border of the proximal fragment, a 22-gauge stainless-steel wire is threaded through the drill hole (Fig. 1,*A*) and then in a circle through the proximal drill hole on the distal fragment. The wire is continued through the site of attachment of the triceps tendon to the olecranon at the same depth as the drill holes. It is then threaded through the lower drill hole of the distal fragment and looped with the wire at the starting point. The anterior surface of the semilunar notch is examined by the surgeon to make certain that, with tension on the wires, the fragments are fixed in a position of anatomical reduction. As soon as the position is judged to be satisfactory, the assistant makes the wires taut by means of two clamps; several twists are then made in the wire ends. The ends of the twisted wire are cut, so that approximately one-third of an inch remains; they are bent over on themselves anteriorly and buried subperiosteally. The wound is closed in layers with interrupted sutures, and a posterior plaster splint is applied from the axilla to the metacarpophalangeal joints. Passive motion is begun in approximately two weeks, if the fracture consists of two fragments; and in three weeks if it is comminuted. Whirlpool-bath treatments, combined with active and passive motion, are carried out before the end of one month. Full motion is usually restored before the sixth or seventh week of treatment.

Twelve cases have been treated during the past seven years, with a follow-up observation period of approximately six to seven years. A complete restoration of function and stability was obtained in eight cases; in four cases, a slight residual defect of flexion and extension occurred, which was explained by the extent of comminution at the time of the fracture and by some narrowing of the semilunar notch. Bony union was obtained in each case. In one instance, it was necessary to remove the wire at the end of six months, since the loop was not turned under the periosteum and the wire produced an area of irritation during flexion and extension.

SENSORY DENERVATION OF THE HEEL FOR PERSISTENT PAIN FOLLOWING FRACTURES OF THE CALCANEUS

(Continued from page 212)

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A UTILITY ATTACHMENT FOR CINEPLASTIC ARTIFICIAL ARMS

BY HENRY H. KESSLER,* M.D., NEWARK, NEW JERSEY

The device described here is an attachment designed to increase the usefulness of cineplastic artificial arms. In cineplasty, the muscles which remain in the amputation stump are used as a motive force to operate the artificial hand. Canals are made in the flexor and extensor muscle groups in the forearm, and in the biceps and triceps muscles in the upper arm. Pegs are inserted through these canals and are attached to stirrups which act directly, through a system of mechanical levers, to open and close the artificial hand. The idea was originally suggested by Vanghetti, and was developed by Putti, Sauerbruch, and others.

The operation of the cineplastic hand by means of cineplastic muscle motors has always had a limited application to the needs of factory workers, farmers and laborers, and others who require a prosthesis which can provide considerable power. It has a distinct advantage, however, because of its automatic and effortless control and, in the case of a forearm prosthesis, because of the avoidance of straps and a shoulder harness. It has been hoped that the prosthesis could be adapted to heavier physical demands.

Many efforts have been made to devise work arms, cineplastically controlled, but without much success. Galeazzi developed an apparatus which was essentially a work tool, attached to cineplastic motors in such a way as to change the position of the work tool, but not to open or close it.

The attachment presented here is one in which the work tool or forceps is directly controlled by the cineplastic motors, so that it is opened or closed automatically (Fig. 1) A system of mechanical levers, acting directly on the arms of the forceps, are connected to the pegs which run through the cineplastic motors. Movement of the muscle motors thu opens or closes the utility attachment with selective pressure to exercise minute and precis force, sufficient to hold objects without crushing them (Fig. 2). This is a function which i not well performed by the standard utility hook, operated by means of a lanyard attachec

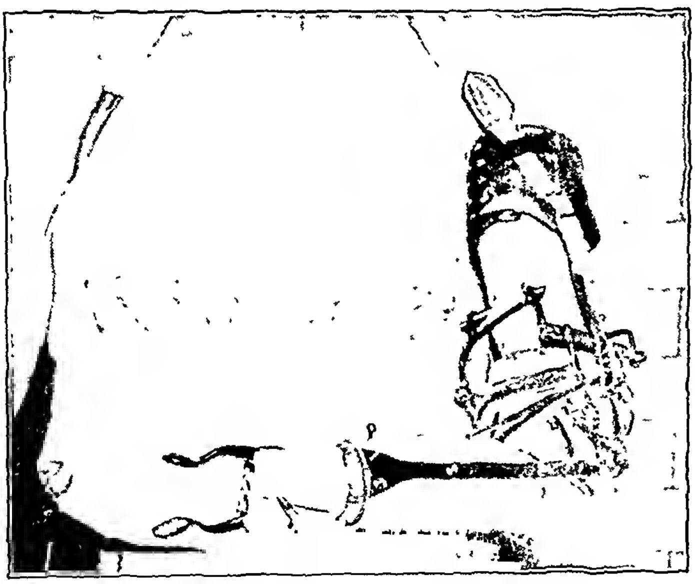

FIG. 1

FIG. 2

Fig. 1: Cineplastic prosthesis with utility attachment. (Reproduced, by permission of Charles C. Thomas, from *Cineplasty* by H. H. Kessler.)
Fig. 2: Selective pressure exerted by cineplastic motors on utility attachment permits grasp of object without crushing it.

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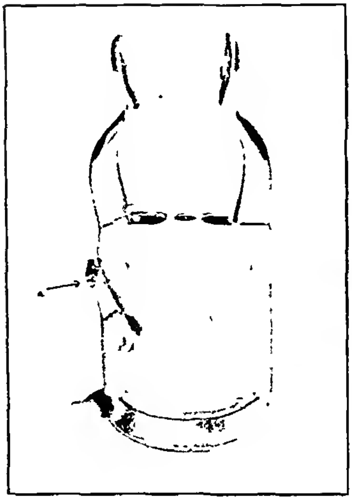


FIG. 3

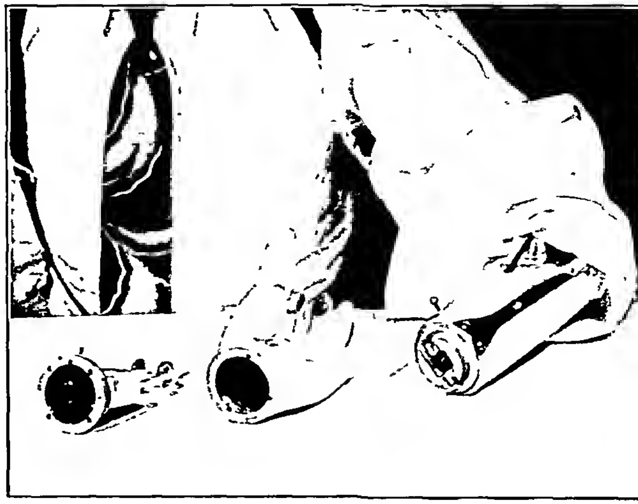


FIG. 4

Fig. 3: Utility attachment with lock device (*a*).
Fig. 4: Interchangeable couplings of cineplastic hand and utility attachment. (Reproduced, by permission of Charles C. Thomas, from *Cineplasty* by H. H. Kessler.)

to a loop passing around the opposite shoulder. When the lanyard is relaxed, the hook snaps shut, due to the spring action of the rubber band fixed to the base of the hook. Thus a small object would be crushed because of the operator's inability to select the exact amount of pressure.

The utility attachment permits the patient with a cineplastic prosthesis to perform work requiring heavier physical demands. The attachment is opened and closed automatically for operations requiring rapid grasp and release. For long-continued holding, the attachment is equipped with a lock device which permits work, without fatigue to the cineplastic motors (Fig. 3).

Another feature of this device is that it can be interchanged with a cineplastic hand. This is accomplished by a special spring coupling which permits the use of the same system of levers for the operation of the hand or forceps (Fig. 4). The utility attachment thus provides a device for heavy work, while the hand permits light activities and satisfies the need for a dress appliance.

CAST TREATMENT OF ACROMIOCLAVICULAR DISLOCATIONS

BY GORDON MONROE MORRISON, M.D., SAN MATEO, CALIFORNIA

A recent comprehensive article on the subject of dislocations of the acromioclavicular joint by Urist [1] includes a bibliography of 101 references. Such a plethora of articles about a relatively simple lesion would indicate that no one is completely satisfied with the methods in common usage. A simple effective method with plaster, which allows the patient free use of both arms, is described here.

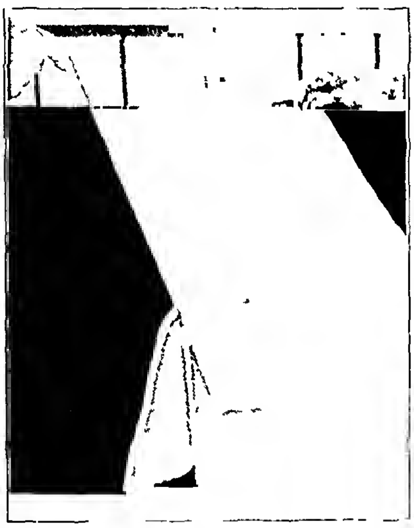


FIG. 1

The part of this procedure which is essentially different consists in keeping the scapula elevated by a sling under the axilla. This sling (Fig. 1) is composed of a fold of half-inch felt, a plaster reverse bandage, and a length of rope over which the plaster and then the felt are draped. The pull is directed upward and slightly medially, and the sling is fixed to an overhead support while the remainder of the device is applied (Fig. 2). While elevation is being maintained constantly, a circular plaster (Fig. 3) is added. A padded shoulder strap is next applied, the cast is allowed to set, and the suspending ropes are cut (Fig. 4).

The axillary crutch molds accurately and gives a comfortable support. Accurate approximation and a somewhat medial pull give an upward thrust, more against the glenoid process than the axillary vessels, and no circulatory or nervous involvement has been encountered. A good grade of fast-setting plaster is essential, and the rope should not be cut until sufficient time for hardening has elapsed. Six weeks is sufficient time for the healing of recent dislocations.

The first patient treated by this method was a young bricklayer with a non-industrial injury, who was reluctant to lose even a single day's work at his present wage scale. He was able to carry on this rather strenuous occupation with no loss of time. The cast was worn for six weeks, and required no adjustments during this period. The patient had an

FIG. 2 FIG. 3 FIG. 4

excellent anatomical and functional end result. In five more consecutive cases, the results were equally good. Only the patients with industrial injuries and one other, a commercial air-line pilot, lost any time from work.

1. Urist, M. R.: Complete Dislocations of the Acromioclavicular Joint. The Nature of the Traumatic Lesion and Effective Methods of Treatment with an Analysis of Forty-one Cases. J. Bone and Joint Surg., 28: 813–837, Oct. 1947.

CONTROL OF POSITION OF LOWER EXTREMITY BY ELASTIC BANDAGE

BY DONALD T. IMRIE, M.D., VICKSBURG, MISSISSIPPI

The technique of applying hot packs in poliomyelitis has, through experience, been modified to meet certain individual variations. Especially when a lower extremity assumes an unnatural position because of poor muscle balance, it is desirable to control the position of that extremity more exactly than can be accomplished by packs alone. By using latex-weave elastic bandages, three or four inches in width, the packs can be held in place more readily than by pinning. At the same time, the wrapping can be so applied as to influence the position of the limb without rigidly immobilizing it.

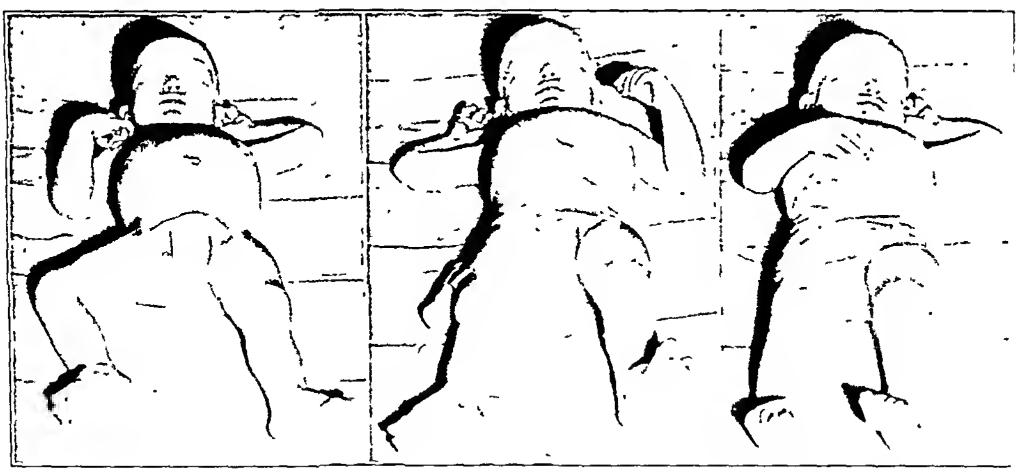


Fig. 1 Fig. 2 Fig. 3

Fig. 1: Position of flexion and external rotation assumed voluntarily by patient who recently has had poliomyelitis. The child has an imbalance of the right lower extremity, and contractures will develop unless the position of the extremity is controlled.
Fig. 2: Shows elastic bandage, which in this case is applied over a thigh pack.
Fig. 3: Tension has been distributed so as to maintain a neutral resting position.

One of the most frequent problems in this condition is the tendency for a lower extremity to fall into a position of external rotation and flexion (Fig. 1). In babies who have involvement of the internal rotators and short adductor muscles, contractures in this position are particularly apt to develop. A hip and thigh pack can be held in place simply by wrapping an elastic-bandage spica in such a way as to control the position of the limb and to maintain a neutral resting position (Figs. 2 and 3).

This simple measure is applicable in a great variety of orthopaedic problems.

THUMB ABDUCTION SPLINT

BY MAJOR J. W. LITTLER AND MAJOR W. J. TOBIN

Medical Corps, Army of the United States

From the Orthopaedic Section, Surgical Service, Cushing General Hospital, Framingham, Massachusetts

Adduction contracture of the thumb is a common finding in injuries of the hand and of the peripheral nerves. The correction of the deformity and the maintenance of proper position are important to the restoration of function. Counterpressure between the thumb and the second metacarpal is necessary, if narrowing of the interosseous space is to be corrected; and effective abduction traction of the thumb is possible only with this adequate counterpressure against the second metacarpal. Without this factor, attempted correction of thumb adduction results only in radial deviation of the entire hand at the wrist. In the authors' attempts to devise a satisfactory method of correcting this deformity, they have developed the splint herein described, and they have found it a most useful piece of apparatus.

FIG. 1

FIG. 2

Figure 1 shows the simplicity of the splint. Effective counterpressure is obtained by the well-padded bar, which rests against the second metacarpal. The transverse palmar bar is made to conform with the normal palmar arch.

Figure 2 shows the splint in place.

The splint is made of one continuous piece of brass welding rod or steel, and is attached to a removable forearm cuff of leather. The "arc" formed should be wide enough to permit a variation in direction of abduction with the carpometacarpal joint of the thumb as the center.

Dynamic splinting must be started early, if the adduction deformity is to be prevented. Surgical intervention will be necessary in long-standing cases in which mobilization by traction has failed.

SEMILUNAR-CARTILAGE KNIVES *

BY F. HAROLD DOWNING, M.D., FRESNO, CALIFORNIA

The two difficulties encountered in removing a meniscus (semilunar cartilage) seem to be the freeing of the posterior third of its peripheral attachment, and the cutting free of the remaining posterior attachment. The ordinary operative instruments are not satisfactory for either of these procedures. With the instruments which the author is presenting. these two technical difficulties may be overcome, and complete excision of the meniscus is possible through a single anterior incision.

The curved knife (Fig. 1, *a* and *b*) is designed to follow the peripheral margin of the meniscus to its posterior attachment, thus freeing the posterior third from its marginal attachments and synovial reflection. The anterior half of the meniscus must first be dissected free, either with the knife or with scissors (Fig. 2). This dissection is carried back to the posterior corner of the femoral condyle or, if on the medial side, to just past the anterior border of the tibial collateral ligament. With the knee flexed acutely, the curved knife is introduced, so that one of its blunt guides passes under the meniscus and the other over the meniscus and internal to the synovial fold (Fig. 3). The curved blade is then pushed against the peripheral margin of the meniscus; and the two guides, plus the curved narrow shaft, direct the blade in such a manner that the meniscus is freed from its peripheral attachment and there remains only its central posterior attachment to the tibia.

This knife does what the Lowe-Breck knife [1] cannot do, chiefly because of the width of its blade and shaft. The width of the Lowe-Breck knife prevents it from following closely the posterior curve around the femoral condyle, and forces the blade back into the popliteal space, thus failing to free the meniscus up to its central posterior attachment. The knife described here has only a small area of maximum width, a narrow, rounded, anatomically curved shaft, two well-rounded blunt guides, and a curved cutting edge, so that, as the blade is pushed forward, there is a tendency for the tissue to be forced toward the central portion of the cutting blade and not to either corner, as may occur with a flat blade. The blade is made of tooled steel which is tempered so that it may be sharpened to a razor edge with a small, pencil-shaped Arkansas stone.

The straight knife (Fig. 1,*c*) is designed to cut off the meniscus at its posterior central tibial attachment, either before or after it has been displaced into the intracondylar notch. The knife has a rounded cutting blade, so that it cuts with a pushing motion. The back of the blade is thickened to prevent breakage.

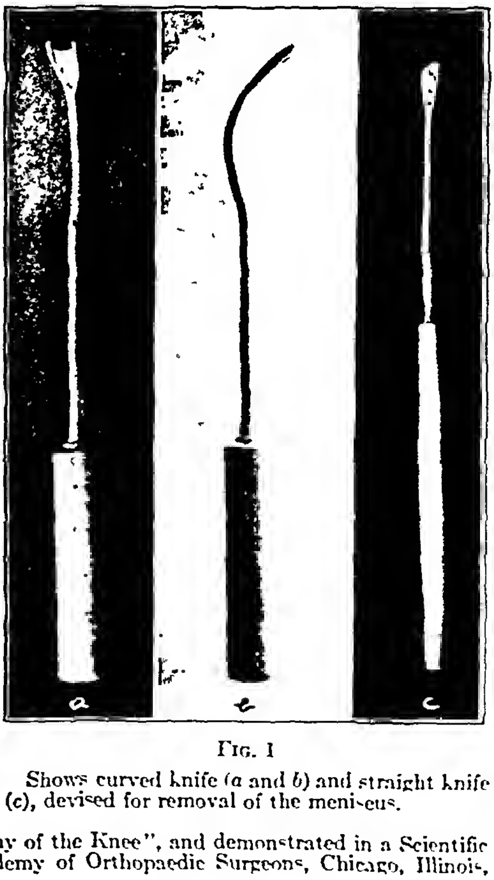


FIG. 1

Shows curved knife (*a* and *b*) and straight knife (*c*), devised for removal of the meniscus.

* Presented in a motion picture entitled "Arthrotomy of the Knee", and demonstrated in a Scientific Exhibit at the Annual Meeting of The American Academy of Orthopaedic Surgeons, Chicago, Illinois, January 25 to 29, 1947.

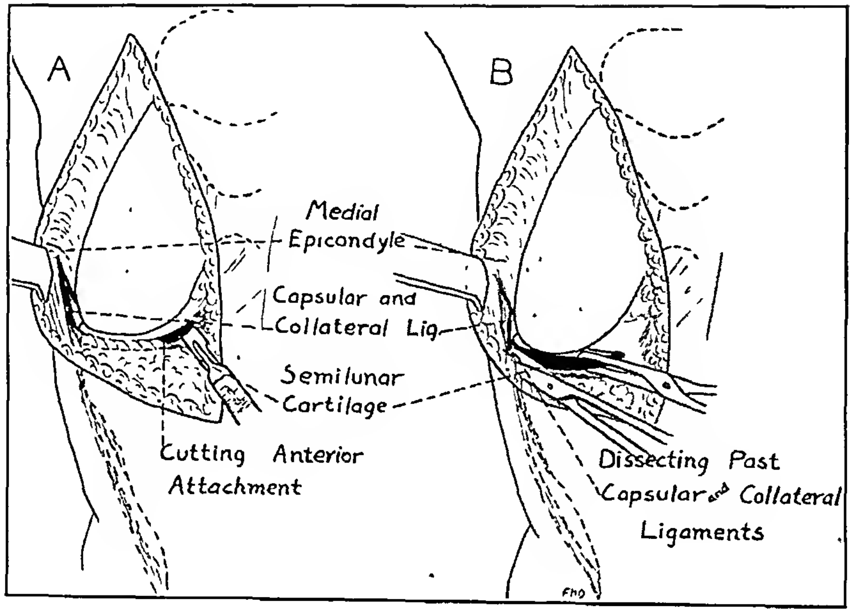
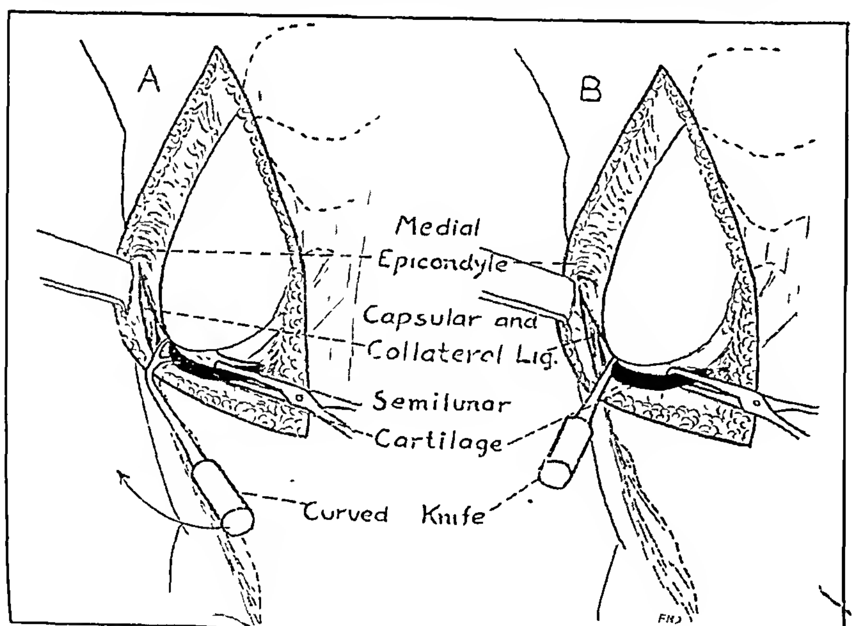


FIG. 2

Removal of the medial meniscus is begun by first cutting free the anterior attachment (*A*), and then dissecting around its periphery to just past the thickened portion of the medial collateral ligament (*B*).



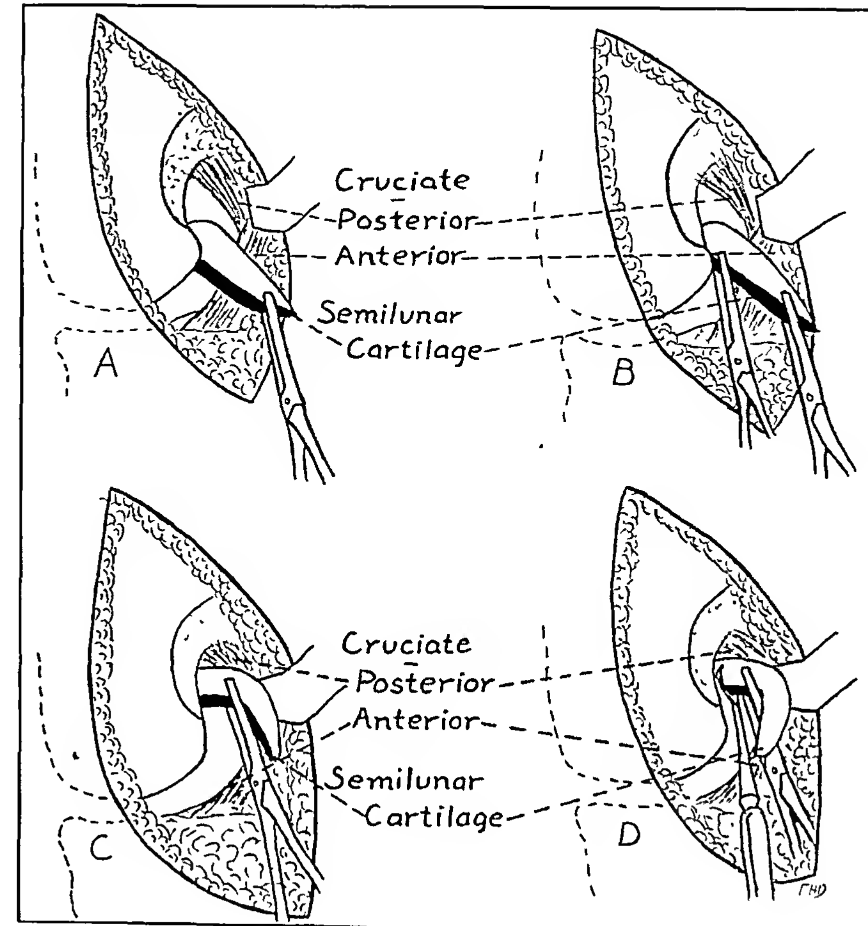


FIG. 4

Fig. 3: The curved knife, with its guide prongs central to the synovial and tibial reflections of the meniscus and its cutting edge past the anterior border of the medial collateral ligament, is pushed with a circular motion around the back of the joint, freeing the peripheral attachments of the posterior portion of the meniscus.

Fig. 4: In *A*, the meniscus is displaced into the intracondylar notch by the operator grasping the tip with an Ochsner clamp and exerting traction. In *B*, a second Ochsner clamp is placed as far posterior as possible on the displaced meniscus. By pushing posteriorly on the second Ochsner clamp, considerably more of the posterior portion of the meniscus becomes visible (*C*). A straight knife, with a blade that cuts with a pushing motion, is inserted (*D*) so that its back is toward the posterior cruciate ligament and its cutting edge is on the posterior attachment of the meniscus. With a few short cuts (pushes), the remaining posterior attachment is severed and the meniscus is removed *in toto*.

The shaft is long and narrow. The usual technique is to dislocate the freed meniscus into the intracondylar notch; it is then grasped with an Ochsner clamp, as far back as possible, and pushed farther posteriorly. The blade of the knife is then introduced, so that the back of the blade is toward the posterior cruciate ligament and the sharp edge is against the central attachment of the meniscus. With a pushing motion, this attachment is severed. If any is missed, it can easily be located with the widened end of the blade, and the same motion can be repeated (Figs. 4 and 6). It is a mistake to pull forward on the cartilage. This places the cartilage at an acute angle to the blade, and may result in a long oblique cut rather than in a short transverse cut at the posterior tibial attachment.

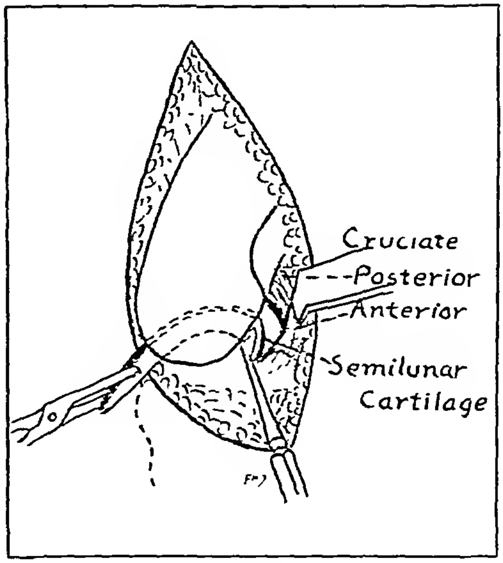


FIG. 5

Shows method of cutting free the remaining attachment of the meniscus without displacing it into the intracondylar notch.

In some instances the meniscus may be removed without its displacement into the intracondylar notch. This may be accomplished by pulling gently on the tip of the meniscus, after its periphery has been dissected free. The region of the posterior attachment may be seen to shake slightly, when viewed through the intracondylar notch. The blade of the

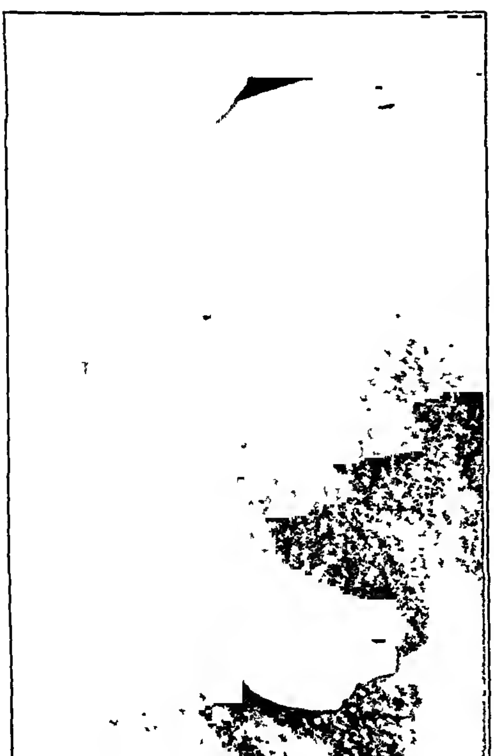


FIG. 6

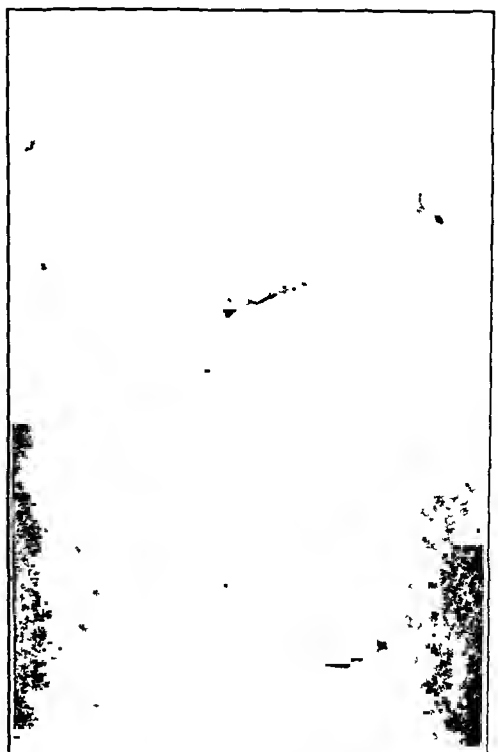


FIG. 7

Fig 6: Medial meniscus removed after displacement into the intracondylar notch

Fig 7: Medial meniscus removed without displacement into the intracondylar notch.

straight-shafted knife is placed against this remaining attachment and, with a pushing motion, it is cut free (Figs. 5 and 7).

These two knives were developed as the result of experience gained from 153 arthrotomies of the knee, performed in the Military Service, and came to be considered as essential instruments by nine different operators. Their use simplified the excision of the medial or lateral meniscus, and enabled the surgeon to close the joint at the end of the operation with a more reasonable degree of satisfaction.

1. Lowe, F. A., and Breck, L. W.: A New Knife for Use in Removing Semilunar Cartilages. J. Bone and Joint Surg., 20: 220–221, Jan. 1938.

APPARATUS FOR CORRECTION OF FLEXION DEFORMITY OF THE KNEE

BY S. RALPH TERHUNE, M.D., BIRMINGHAM, ALABAMA

The apparatus depicted has been employed successfully for conservative correction of flexion deformity of the knee. This was devised on the principle described by Horwitz[1]. The turnbuckles have, however, been replaced by rubber bands. This method has proved

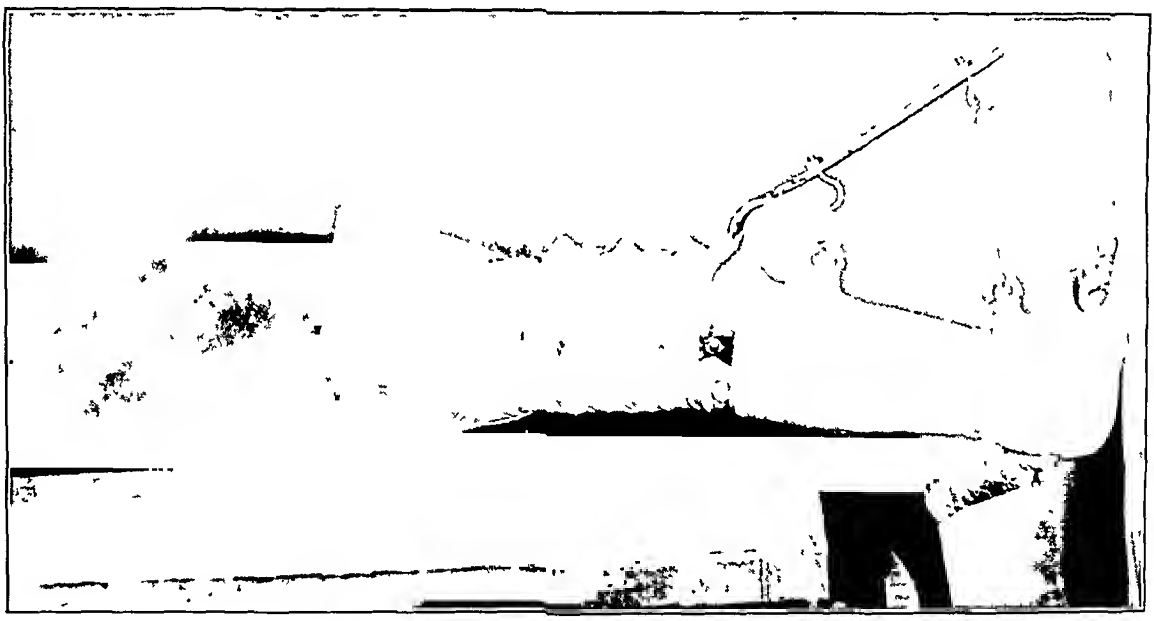


Fig. 1

to be superior to turnbuckle traction, in that the bands stay in place better and do not have to be changed.

The most important advantage is that the patient can constantly exercise the muscles and the knee joint, thus eliminating to a great extent the atrophy and stiffness which accompany fixed turnbuckle traction. This turnbuckle traction must be released for frequent periods, in order to prevent the development of pressure ulcers. Rubber-band traction can be maintained constantly, with the patient doing flexion exercises, and *pressure ulcers are much less apt to occur.*

1. Horwitz, M. T.: Conservative Method of Correcting Flexion Deformity of the Knee Complicated by Posterior Luxation of the Tibia. J. Bone and Joint Surg., 19: 522–523, Apr. 1937.

APPARATUS FOR MAINTAINING ROTATION OF LOWER EXTREMITY WHILE IN TRACTION

BY HARRY R. WHEAT, M.D., SPRINGFIELD, MASSACHUSETTS

A certain number of fractures of the neck and trochanter of the femur are best treated by traction. The Russell method seems to be the most satisfactory. This or any other type of traction presents two difficulties: First, if skin traction is used, the adhesive requires constant watching for slipping and skin irritation. Second, there is also the difficulty of holding the limb in internal rotation until union has taken place,—thereby preventing a distressing outward-rotation deformity.

To overcome these difficulties the following routine has been used for the last two years with satisfactory results:

The patient is anaesthetized with a small amount of pentothal sodium. A Kirschner wire is inserted through the lower portion of the tibia, and the ends are left uncut. A well-padded plaster boot is applied with the dorsum of its foot and ankle cut away to allow active motion. After manipulation and reduction of the fracture, and after full internal rotation has been obtained, the apparatus is applied (Fig. 2-A) and traction is instituted. Complete reduction is necessary to prevent torsion strain of the knee.

The apparatus used consists of two tubes, twenty-six inches long, held by movable crosspieces at each end, which allow the width of the frame to be adjusted. The tubes are slotted to allow free excursion of the vertical assembly. The uprights are joined at their bases to a freely movable crosspiece to which is fixed a small foot plate. The uprights are furnished with adjustable fixtures with apertures which loosely hold the Kirschner wire. Up-and-down adjustment of these fixtures provides the desired degree of rotation.

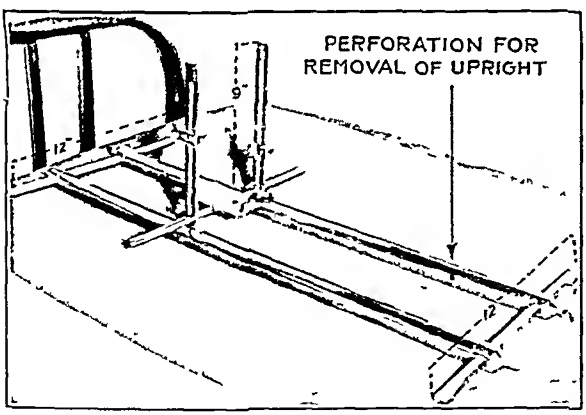


FIG. 1
Showing apparatus assembled.

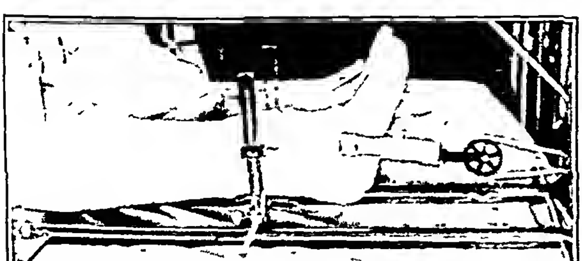


FIG. 2-A FIG. 2-B
Showing apparatus in use.

A SELF-TURNING SLING DEVICE

BY HERBERT E. HIPPS, M.D., WACO, TEXAS

The simple device described here makes it possible for a patient in a large, heavy body cast or a hip spica cast to turn himself, easily and without help, from his back to either side, and to maintain himself securely and comfortably in the desired position. It can be constructed and assembled at any hospital, by a nurse or orderly. The component parts are not expensive, and may be purchased at any hardware store.

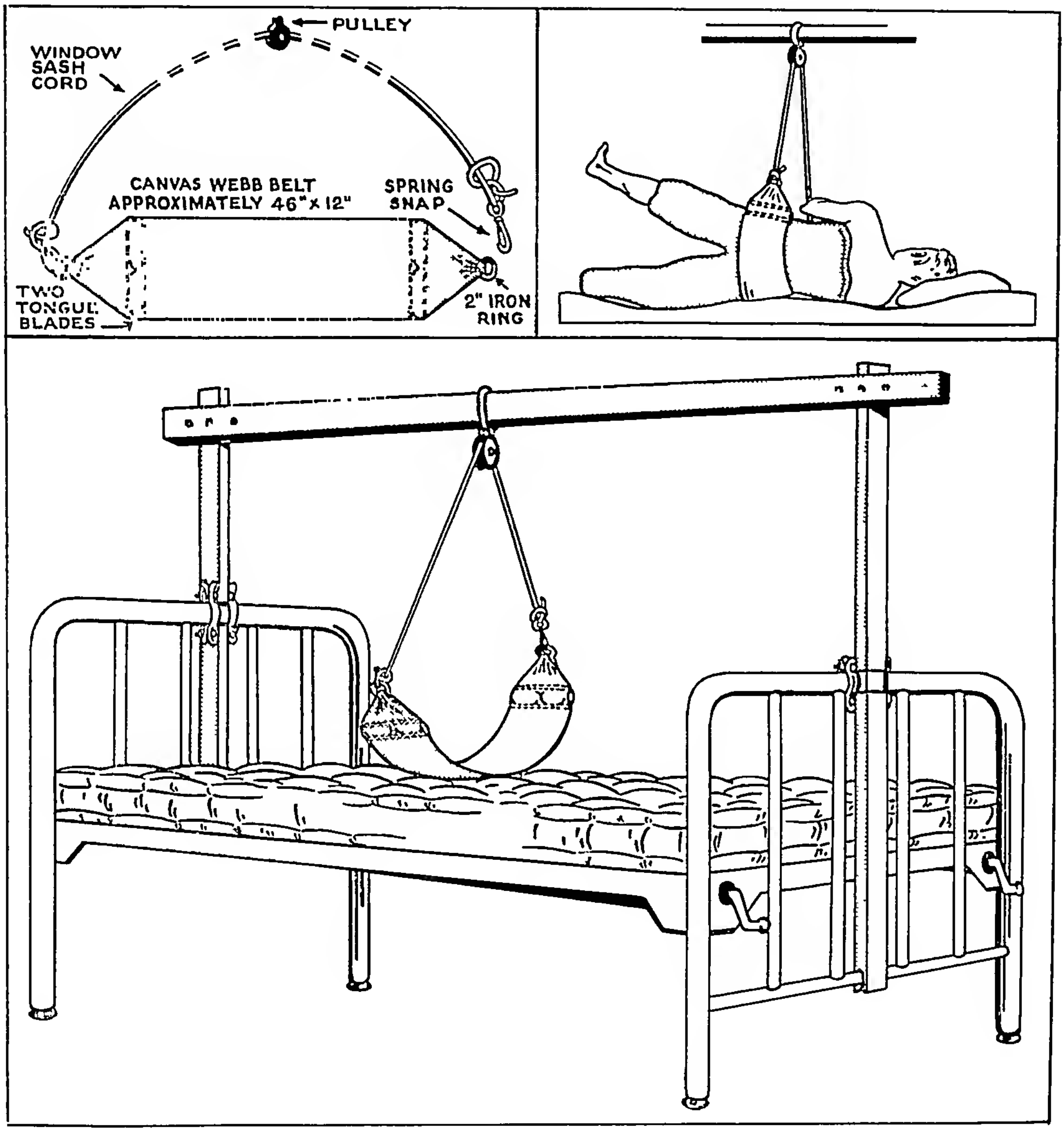


FIG. 1

The sling is of heavy duck or canvas material. Harness rings are sewed into each end. Transversely sewed-on linear pockets, into which tongue blades are thrust, prevent the sling from rolling up (Fig. 1).

The rope is window-sash cord, the pulley any ordinary one, and the spring snap is a device used on harness. An overhead bed frame, of the design which most hospitals usually have, is suitable for the pulley attachment.

The sling must support the patient at his approximate balancing center, usually about the pelvis. It must actually support or lift the patient, holding him about a quarter of an inch off the bed surface. The patient can easily turn himself in bed by pulling the rope on the side to which he wishes to turn.

RESULTS OF RECENT STUDIES AND EXPERIMENTS CONCERNING METALS USED IN THE INTERNAL FIXATION OF FRACTURES

BY C. S. VENABLE, M.D., AND WALTER G. STUCK, M.D., SAN ANTONIO, TEXAS

A Synopsis *, Prepared by Dr. Venable

At present, bone plates and screws are being placed upon the market, which may or may not be of suitable quality for use in bone-plating procedures. The reports on the metals used for such plates have been confusing. The purpose of this review is to clarify these reports.

In January 1941, the Committee on Fractures and Other Traumas of the American College of Surgeons, meeting in New Orleans, appointed a Subcommittee on Screws and Plates, composed of Dr. C. S. Venable, Chairman, Dr. Clay Ray Murray, and Dr. Huber Wagner. This Subcommittee was directed to undertake a comparative study of various metals with respect not only to their inertness in the tissues and resistance to corrosion, but also to their physical and mechanical qualifications to meet the requirements of bone surgery.

After a year the Subcommittee presented a report of progress, together with plans for further study, to the Committee on Fractures and Other Traumas of the American College of Surgeons [1] at its Washington meeting. Since no funds for this proposed work were made available by the Regents of the College, the matter was referred to the Committee on Medical Research of the Office of Scientific Research and Development; and a grant for further research was made in 1942. With this grant from the Committee on Medical Research, the whole problem was submitted to Columbia University, where Professor Colin Fink, head of the Graduate Engineering Department, was assigned to study and report the electrochemical and physical findings and make recommendations regarding the adaptability and applicability to bone surgery of the materials submitted for study, in accordance with specifications based on clinical data supplied by the Subcommittee. Dr. Clay Ray Murray was assigned to undertake the study of tissue reaction to these metals in the animal experiments. These were to be conducted at Columbia Medical Center, since Dr. Murray had all the needed facilities at hand for such experiments *in vivo* and was thoroughly familiar with the subject and the ends sought.

The materials selected for this study, which in the opinion of the Subcommittee seemed most nearly to meet the required qualifications, were 18–8 stainless steel plus molybdenum (SMo), 19–9 stainless steel passivated in nitric acid, Vitallium, and tantalum.

In August 1944, the Subcommittee met in New York to review the data at hand and to prepare its report. At that time the experiments carried on by Professor Fink had not been completed, and the final report was not available. Therefore, the Subcommittee reported on the basis of the information then available:

"1. Vitallium, '19–9 stainless steel', and '18–8 SMo stainless steel' are inert in the tissues in descending order of excellence.

"2. Combinations of these metals should not be used in any single operation.

"3. The ability to withstand functional strain during the healing period is greater in the 'stainless steels' than in the Vitallium plates and screws which were tested. However, more recent improvements in production of Vitallium plates and screws entailing the use of x-ray testing for casting defects have produced Vitallium plates and screws which are on a par with the two 'stainless steels' in regard to the resistance to functional strain.

"4. Plates of either of the 'stainless steels' considered must be machined rather than stamped and the screws must be precision machined.

"5. All screws should be of the standard machine type with sharply cut threads and should have a short self-tapping end with a right-angle Mills cutting edge.

"6. Screws without a tap and tapering screws are inadvisable in living bone unless a tap for the screw is made in the bone before the screw is inserted.

"7. The heads on all screws should be made as flat as possible since countersinking of these screws in the plates is inadvisable. The countersunk hole weakens the plate.

"8. 'Stainless steel' plates and screws should be surface marred as little as possible during application. If badly scratched or abraded they are subject to increased corrosion in the tissues. Neither plates nor screws should ever be used a second time. It is obvious that non-slipping screw drivers are needed for the insertion of screws and that the plates should be protected from scratching by the instruments with which they are handled.

"9. Following bending, deep surface scratching or severe strain 'stainless steel' plates and screws show increased corrosion in the tissues and increased liability to breakage from fatigue strain.

"10. From studies of weight loss after exposure to the tissues and to blood serum under varying con-

* Paper was presented in full at the Annual Meeting of The American Academy of Orthopaedic Surgeons, Chicago, Illinois, January 28, 1947.

ditions both before and after strain, it is apparent that there may be no fear of deleterious poisonous action from any of the three metals cited as satisfactory.

"11. No screw holds well in cancellous bone. Wider threads to increase the holding power merely intensify the concentration strain on the screw with an increased absorption rate of calcium about the screw. Screws attempting to fix cancellous bone should have a firm grip on the distal cortex or a bolt should be used in place of them.

"12. All screws in long bones should penetrate both cortices where possible and should be inserted at right angles to the surface of the plate holes or to the surface of the bone if no plate is used. If placed at an angle in bone without a plate, the screw head should be countersunk to prevent shearing strains on the neck of the screw. This latter procedure should always be followed in the use of transfixion screws which are at an angle to the surface of the bone.

"13. Plates should be of adequate length and with a sufficient number of screw holes to distribute the strain so that no undue strain is borne by any individual element, plate or screw.

"14. The drill holes should be made by a drill slightly smaller than the shank of the screw without its thread and the drill should be carefully protected against wobbling or reaming as the hole is drilled. Excessively high speed drills are to be avoided."

By macroscopic examination, the tissues adjacent to the steel screws and plates showed evidence of discoloration. Biochemical examinations of the adjacent tissues to determine which metals had been dissolved were not made, although this test was recommended in the original agenda of 1941 for this review and study.

On the basis of the data submitted, it was agreed by the Subcommittee that 18–8 SMo steel, designated as "Specifications 316 and 317" by the American Steel and Iron Institute, was suitable for internal fixation of fractures for the period of healing. This restriction did not apply to Vitallium, which could be left in the body indefinitely.

The report of the Committee on Medical Research was completed in June 1944, and forwarded to the National Research Council. The Subcommittee only became aware of this in May 1946. Thus when the Subcommittee met again in New York, in December 1944, it did not have access to the experimental findings of the Committee on Medical Research. The final report of the Subcommittee was then prepared and submitted to the Fracture Committee of the American College of Surgeons at Atlantic City, in January 1945. This explains the inconsistencies in the two reports. In the Subcommittee's report, it was stated that there was "marked variability of the individually cast Vitallium plates". The consequent threat of breakage, while changed qualitatively (by x-ray review before use) "remained quantitatively unchanged in contradistinction to the stainless steels". In addition, in these tests, "there was demonstrated a marked variability in the individually cast Vitallium plates. This amounted to a thirty percent variation" as related to the strength of such plates.

Now it is learned that Professor Fink's report to the Committee on Medical Research actually stated that in corrosion tests of nickel-plated screws, in which electrolytic etching was performed to determine the thickness and sharpness of the thread: "Readings of thickness often varied as much as 30% or more". This obviously has nothing to do with the suitability of Vitallium plates for internal fixation.

Elsewhere in the Subcommittee's report it is asserted: "This variability in Vitallium was true even in those plates which had been x-rayed and found by x-ray to be without casting deficiencies, carbon spots or air bubbles". "The ability to withstand functional strain during the healing period is greater in the 'stainless steels' than in the Vitallium plates and screws which were tested. However, more recent improvements in production of Vitallium plates and screws entailing the use of x-ray testing for casting defects have produced Vitallium plates and screws which are on a par with the two 'stainless steels' in regard to the resistance to functional strain."

In the report of the Committee on Medical Research, however, an opposite view is taken. "Table No. VII generally indicates slightly larger corrosion rates for strained plates than for unstrained plates, except for Vitallium. . . . In straining, the plates were bent to a 90 degree angle and straightened. This treatment caused the Vitallium to display large crystals at the site of the bend and also caused cracks to form!" The steels, after such extreme bending, develop anodic and cathodic points which become specific foci for corrosion. This is a much worse complication than the formation of crystals or cracks.

The Subcommittee concluded its report as follows:

"Tantalum is not suitable for use as plates or screws for internal fixation of fractures.

"Of the two stainless steels, the overall consideration of this Committee is that the equivalent of 18–8 SMo steel is the more desirable of the two stainless steels, as designated by the American Steel and Iron Institute, Specifications 316 and 317.

"It would, therefore, be the opinion of this Committee that Vitallium under the conditions in this discussion and the stainless steel identified by the American Institute and the above stainless steel are the two metals which we recommend as acceptable."

"At this time particularly this Committee feels that such standards should be created upon sound principle to be submitted to the Bureau of Standards and subsequently submitted to the Department of

Commerce for its approval, and then to the Congress to be placed in the Food and Drug Act in order to assure for the future that only materials which meet these requirements may be offered for sale".

So far, the Bureau of Standards has devoted most of its attention to torsion strength, ductility, and hardness of metal plates and screws, rather than to freedom from electrochemical effects in the body. The result has been that various types of stainless steel have been endorsed which are definitely deleterious in the body. Also, instrument makers are still selling "stainless steels" with varying properties which are not universally suitable in the body.

It is unfortunate that these contradictions have appeared in the various official reports on this subject, because the individual surgeon is thus left more confused than ever. The original plan of the Fracture Committee of the American College of Surgeons was to establish a specific standard which could be depended upon by everyone. This objective failed because divergent opinions were voiced by different committees, and no single accepted view was expressed by all. However, the Fracture Committee now has access to all the reports on the effects of metals on bone, and should be in a position to proceed to some type of standardization in conjunction with the Bureau of Standards.

REFERENCES

1. Committee on Fractures and Other Traumas, American College of Surgeons: Report of Subcommittee on Plates and Screws. Proc. Twenty-third Annual Meeting, Atlantic City, N. J., Jan. 26–27, 1945.
2. Committee on Medical Research, Office of Scientific Research and Development (Report No. 17, by Colin G. Fink): Use of Metal in Internal Fixation of Human Bone Fractures, Dec. 1944.
3. Venable, C. S., and Stuck, W. G.: The Internal Fixation of Fractures. Springfield, Illinois, Charles C. Thomas, 1947.

DISCUSSION

Dr. J. Albert Key, St. Louis, Missouri: Dr. Venable and I have quarreled for years in a friendly manner over the relative merits of Vitallium and stainless steel. Vitallium is the better material to use if you want to avoid irritation in the tissues or electrolytic reaction. It has the disadvantage that it cannot be machined or drawn into wire; it must be cast. The surgeon who uses it should have the ability to judge the mechanical factors that it will be called upon to withstand. We are going to have plates and screws of stainless steel or of Vitallium torn out or broken. I know a good deal about bone surgery and internal fixation, but I have had plates fail, not because of anything inherently wrong with the material used, but because they were used unwisely. You have to add external fixation in cases where internal fixation is not enough. I have used dual plates in recent years, omitting external fixation. You cannot do it with ordinary plates, because they will break or bend or tear out, whether they are Vitallium or stainless steel. My opinion is that there is a place for both metals.

One must not put two types of stainless steel in the same wound. I have reported cases in which there was electrolysis with very marked absorption around the screws; when I removed those screws they were black, yet they had been sold as stainless steel. I do not know which of the stainless steels is the better. With Vitallium, we always know where we stand.

Dr. Leonard Peterson, Washington, D. C.: Materials for internal fixation should be of the highest quality so that, with proper surgical technique, no failures will occur as a result of electrolysis, faulty design, or inadequate strength. The material should be physiologically inert in the body; and in this respect we have two metals which are suitable, Vitallium and the stainless steel known as 18–8 SMo. The designation of 18–8 SMo is applied to a range of high-alloy stainless steels, containing from 15 to 19 per cent. chromium, 8 to 14 per cent. nickel, and 2 to 4 per cent. molybdenum. This explains the designation, SMo, which means steel fortified with molybdenum. If we speak of stainless steels as a group, we will encounter many outside this formula which are not inert and which, if mixed with each other, can set up serious electrolysis. However, 18–8 SMo meeting proper specifications is physiologically inert for all practical purposes, and compares favorably with Vitallium in this respect. In addition to the specified composition, the hardness of the final product should be specified, since variable hardness may cause electrolytic reaction. A hardness of Rockwell 30 to 35 on the C scale has been adopted as standard.

Unfortunately, the physical characteristics of metal have not received proper emphasis in the search for inert material. In an effort to correct existing deficiencies in composition, design, and manufacturing, new tentative Army specifications were prepared in cooperation with the National Bureau of Standards. The metal adopted was 18–8 SMo, hardness 30 to 35 Rockwell C. Plates were limited to six sizes, which include practically all the lengths previously made in eleven sizes. For increased strength and rigidity, plates were made with a straight mid-section, similar to the design used in Canada. They combine the desirable features of the Sherman catenoid plate,—namely, uniform bending, and of the Venable straight plate,—namely, increased strength in the mid-section, where it is needed. Nearly everyone concerned agrees that this new type could replace both of the other types of plates without any advantage being lost. The plate should be bent by suitable bending irons to fit the bone before application, in order to avoid a spring tension effect on the screws. Precautions against bending as required are, in my opinion, without clinical importance

Screws have been adopted with a cruciate head, which possesses advantages similar to the Phillips head. The Phillips head cannot be made economically in 18–8 SMo because of its hardness, and the simple slotted head is obviously inadequate. Two improved flutes are provided, and a pilot or guide point is an optional feature. The drill point of optimum diameter, based on numerous tests at the Bureau of Standards, is made of distinctive shape and length, of the same metal as the plates and screws, and is unbreakable, in contrast to the frequent breakage of drills previously encountered.

While the inert quality of Vitallium is recognized, its strength and fatigue resistance are inferior to 18–8 SMo and, furthermore, no method of manufacture, inspection, or testing has been verified which will absolutely exclude defective Vitallium plates. In the report of the Committee on Fractures and Other Traumas of the American College of Surgeons, Atlantic City, New Jersey, January 1945, Dr. Venable's Subcommittee on Plates and Screws reported: "Vitallium was found in many instances to be the complete equal of the SMo steel as regards these tests, but throughout the investigation there was demonstrated a marked variability in the individually cast Vitallium plates. . . . The stainless steel showed a remarkable uniformity on the other hand. . . ." This report is based on the research conducted by Professor Colin Fink at Columbia University, under the auspices of the Office of Scientific Research and Development. The final report by Professor Fink concluded that Vitallium and 18–8 SMo were equal in corrosion resistance. Plates were tested by bending and straightening. This caused the Vitallium to display large crystals at the site of the bend and also caused cracks to form. While Dr. Venable has previously claimed that Vitallium is the only metal which appears to be uniformly inert, the results shown in the Fink report indicate differently, since both Vitallium and 18–8 SMo were found suitable from the physiological standpoint. In respect to the physical properties investigated by the National Bureau of Standards, I quote the following from a report by Dr. L. B. Tuckerman, December 17, 1946: "Our examination and tests of Vitallium bone plates have confirmed the statements made in the committee report about the variability of the mechanical properties of these plates. Several Vitallium plates removed from soldiers' legs in Army hospitals because of brittle fractures showed only local brittleness. . . . We were unable to correlate these areas of local brittleness with any chemical segregation or differences in microstructure or with local variations in indentation hardness."

"The seriousness of the results of a single broken plate in a man's leg makes us reluctant to write any specification for bone plates which does not ensure that *no single* brittle plate shall be accepted. . . . The presence of local brittleness is not revealed by x-ray inspection.

"So far as we can see the absolute exclusion of the possibility of occasionally accepting Vitallium plates having local brittleness could only be obtained by reliable non-destructive tests which could be applied to each individual plate. We know of no such tests. . . .

"We have also made many tests of 18–8 SMo plates. Our tests have confirmed the statements made in the committee report about the uniformity of this material. Plates cold worked to the same Rockwell C hardness gave uniform strength. Plates of higher Rockwell C hardness gave, as was to be expected, higher strength. In no case did we have a brittle failure. The plates could be bent and straightened many times without brittle fracture . . ."

In conclusion Dr. Tuckerman states: "At present as explained above we can only see our way clear to write specifications for plates made of 18–8 SMo".

Dr. Clay Ray Murray, New York, N. Y.: I would like to augment some of the things Dr. Peterson had to say. I spent almost three years on the investigation of this problem in cooperation with Professor Colin Fink of the Engineering Department at Columbia University. These studies, made under the auspices of the Office of Scientific Research and Development, were in large part the basis for the report rendered to the Committee on Fractures and Other Traumas of the American College of Surgeons. The factual findings were that 18–8 SMo stainless steel, 19–9 stainless steel, and Vitallium were all acceptable for use as plates and screws. It was agreed that, of the three, Vitallium was the most inert in living tissue. It was further agreed that none of the three produced sufficient reaction to cause physiological disturbance, interfering with the healing of bone or soft parts. It was agreed that mixing two different types of metal might cause physiological disturbance, and that this practice was distinctly undesirable. It was factually demonstrated that, in response to mechanical strain tests, the stainless steels were remarkably constant, but that there was a considerable variation among the individual Vitallium castings in their response to the same tests. These being factual findings, there could be no disagreement among the Committee members in regard to them.

Dr. Walter G. Stuck (closing): I appreciate the remarks of the discussors. The subject is too vast to cover in a few minutes. I therefore feel like our Open Forum speakers who, when asked questions, reply: "You will find the subject well covered in my latest book".

JOSEPH B. L'EPISCOPO

1890–1947

On September 5, 1947, after a protracted illness, Joseph B. L'Episcopo died in New York. The medical profession lost an esteemed practitioner of medicine and a well-known orthopaedic surgeon.

For about seven years prior to his death, he was Professor of Orthopaedic Surgery at the Long Island College Hospital, where he had served his internship.

During World War I, Dr. L'Episcopo served as First Lieutenant in the Medical Corps of the United States Army. After returning to private practice, he devoted himself to the development of the Orthopaedic Department of the Long Island College Hospital. He also became the Director of Orthopaedic Surgery at Kings County Hospital, Carson Peck Memorial Hospital, Bushwick Hospital, House of St.Giles the Cripple. and many other institutions throughout Brooklyn and Long Island.

As a Fellow of the American College of Surgeons, he was deeply interested in its activities. He was a member of The American Orthopaedic Association and a charter member of The American Academy of Orthopaedic Surgeons, and he was extremely interested in their activities.

Dr. L'Episcopo was born in Italy, and came to this country at the age of eight. Among the outstanding features of his professional career in the community in which he lived was his intense loyalty to organized medicine in all its branches. He was a frequent contributor to the literature in his specialty, a keen student of anatomy throughout his life, an able and competent surgeon, and a teacher. Perhaps his most characteristic traits were his gentleness of manner and firmness of purpose. It was his desire at all times to lend a helping hand to his students, interns, and residents, by whom he was revered. Up to three days before his death, he was still making plans for the betterment of the Long Island College of Medicine and for the improvement of services of the various members of his Staff. He possessed a gentleness tempered with firmness, an intelligence impregnated with years of clinical experience,—a teacher, a scholar, and above all a gentleman.

His passing is a distinct loss, and an untimely one, to the profession and the specialty which he served so nobly. Those who had the privilege of knowing him intimately will never forget his influence on their lives.

PIERO PALAGI

1879–1947

Professor Piero Palagi, one of the best known and most colorful of the orthopaedic surgeons in Italy, died in Florence on March 18, 1947. He was born on December 29, 1879, in Bibbiena, Tuscany. He was graduated from medical school in Florence in 1902, and did postgraduate work at the hospitals for internal medicine and general surgery in Florence until 1905. In 1906 he became associated with the great orthopaedic hospital, *Istituto dei Rachitici*, in Milan, where he worked for nearly three years under the guidance of the noted Italian orthopaedic surgeon, Galeazzi. Subsequently Palagi did postgraduate work at other orthopaedic institutions abroad, mostly in Germany.

During the first World War he performed distinguished service as a military surgeon, and was head of the first specialized service for the treatment of bone and joint casualties. After the war, Palagi was nominated chief of the section of orthopaedic and traumatic surgery in the Department of Surgery at the University of Florence; he directed that service from November 1918 to May 1923, when he became chief of the *Istituto Ortopedico Toscano,* the orthopaedic hospital of the University. From a relatively modest orthopaedic hospital (thirty beds in 1923, when Palagi took over its direction), the *Istituto Ortopedico Toscano* developed gradually during the following twenty-four years into one of the finest orthopaedic institutions in Italy.

Since 1925, Palagi had occupied the Chair of Orthopaedics and Traumatic Surgery at the University of Florence. With almost a quarter of a century of teaching and innumerable courses of lectures to general practitioners, country physicians, health officers, and nurses, Palagi contributed greatly to the diffusion of orthopaedic knowledge throughout the profession and to the realization of the importance of orthopaedic surgery which, until a few years ago, had been considered but a stepchild of surgery. Together with Putti, his lifelong and intimate friend, Palagi undertook a true crusade for the early recognition and treatment of congenital dislocation of the hip, a disease frequent in Italy, particularly in Tuscany.

In more than fifty scientific papers, monographs, and reports at Italian and international meetings, he made several important contributions.

Aside from his qualities as surgeon and teacher, Palagi was outstanding for his personality, which left a deep and lasting impression on all who have had the privilege of being associated with him. He was a gentleman in the noblest sense of the word, straightforward and courageous at a time when few people in Italy had the fortitude to stand for their convictions. He gave all of himself to his profession. He is deeply missed by his many friends and associates.

News Notes

THE AMERICAN ACADEMY OF ORTHOPAEDIC SURGEONS

The Fifteenth Annual Convention of The American Academy of Orthopaedic Surgeons will be held at the Palmer House, Chicago, January 24, 25, 26, 27, 28, and 29, 1948, under the presidency of Dr. Rex L. Diveley.

Registration will begin at nine o'clock Saturday morning, January 24. Scientific and Technical Exhibits will be ready for inspection at that time. During the afternoon the Audio-Visual Education Program will be presented under the chairmanship of Dr. Charles N. Pease. At seven o'clock Saturday evening the Instructional Course Dinner will be given, at which time an "Information Please" program will be presented. This will offer to members present an opportunity to "stump the panel of experts".

The Audio-Visual Education Program will continue on Sunday morning from nine o'clock until noon. The Instructional Courses will begin at two o'clock Sunday afternoon and continue until noon on Monday. The following Courses will be offered.

Course I

Abnormal Anatomy of the Lumbosacral Region with Reference to Low-Back Pain........ Dr. Theodore A. Willis
Roentgenography in Low-Back Pain........ Dr. Albert Ferguson
The Medical Aspects of Low-Back Pain........ Dr. J. G. Kuhns
The Conservative Treatment of Low-Back Pain........ Dr. Paul C. Williams
The Operative Management of Low-Back Pain........ Dr. Joseph S. Barr
Lumbosacral Fusion........ Dr. David M. Bosworth
Surgical Treatment of Low-Back Pain........ Mr. H. Osmond Clarke

Course II

Postoperative Care........ Dr. Walter G. Maddock

Course III

Medical Aspects of Arthritis........ Dr. Richard H. Freyberg
Orthopaedic Treatment of Arthritis........ Dr. Carl E. Badgley

Course IV

Anatomy of the Hand........ Dr. J. E. Markee

Course V

Vascular Phenomena in Orthopaedics........ Dr. Donald S. Miller
Dr. David I. Abramson

Course VI

Plastic Surgical Problems Related to Adult Orthopaedics........ Dr. Paul W. Greeley
Principles and Practice of Plastic Surgery as Related to the Care of Crippled Children........ Dr. H. R. McCarroll

Course VII

The Treatment of Acute Hematogenous Osteomyelitis........ Dr. Robert C. Robertson

Course VIII

Vascular Tumors of Bone........ Dr. Henry W. Meyerding
Dr. Dallas B. Phemister
Dr. David G. Pugh
Dr. Bradley L. Coley
Dr. Norman L. Higinbotham

Course IX

Painful Hips in Children........ Dr. Leo S. Lucas

Course X

Tuberculosis of the Spine in Children . . . . . Dr. Edwin F. Cave
Tuberculosis of the Lower Extremity in Children . . . Dr. Fremont A. Chandler
Tuberculosis of the Upper Extremity in Children . . . Dr. George J. Garceau

Course XI

Seminar on Scoliosis . . . . . Dr. Joseph C. Risser

Course XII

Psychosomatic Problems in Orthopaedic Surgery . . . Dr. J. Vernon Luck

Course XIII

Hip Surgery . . . . Dr. Paul H. Colonna

Course XIV

Endocrines in Bone Metabolism . . . . Dr. Irvin Stein

Course XV

Seminar on Amputations of the Lower Extremity . . . Dr. Rufus H. Alldredge

Course XVI

Practical Foot Problems . . . . . Dr. Walter R. Fischer

Courses XVII & XXXIV

Disability Evaluation . . . . . Dr. Earl D. McBride

Course XVIII

Seminar on Plastic Surgery . . . . . Dr. Paul W. Greeley

Course XIX

Anatomy of the Shoulder . . . . . Dr. Claude N. Lambert
Anatomy of the Hip . . . . . Dr. John J. Fahey

Course XX

Scoliosis . . . . . Dr. Harold E. Crowe
Dr. Wm. H. Von Lackum
Dr. John R. Cobb
Dr. Joseph C. Risser

Course XXI

Muscle Physiology . . . . . Dr. Charles O. Bechtol

Course XXII

The Surgical Treatment of Poliomyelitis . . . Dr. C. E. Irwin

Course XXIII

Chemistry of Bone Lesions . . . . . Dr. Irvin Stein

Course XXIV

The Cerebral Palsies . . . . . Dr. W. M. Phelps

Course XXV

Arthroplasty of the Hip . . . . . Dr. M. N. Smith-Petersen

Course XXVI

Treatment of Congenital Club-Foot . . . . Dr. J. Hiram Kite

Course XXVII

Conservative Management of Lesions of the Lumbosacral Spine . . . . Dr. Paul C. Williams

COURSE XXVIII

Surgical Approaches: Upper Extremities................Dr. H. Herman Young
Surgical Approaches: Lower Extremities................Dr. Wm. Schnute

COURSE XXIX

Internal Fixation of Fractures........................Dr. Walter G. Stuck

COURSE XXX

Seminar on Arthritis..................................Dr. Richard H. Freyberg

COURSE XXXI

Hand Surgery..Dr. Walter C. Graham

COURSE XXXII

Roentgen Diagnosis of Bone Tumors.....................Dr. Albert B. Ferguson

COURSE XXXIII

Roentgen Diagnosis of Bone Tumors.....................Dr. Albert B. Ferguson

COURSE XXXV

Hemipelvectomy..Dr. Don King

On Monday afternoon, Tuesday, Wednesday, and Thursday morning, the Scientific Program will be given.

There will be Executive Sessions at noon on Tuesday and at noon on Thursday, for members only.

The following program has been selected by the Program Committee under the chairmanship of Dr. T. Campbell Thompson.

MONDAY, JANUARY 26

Afternoon Session

Occurrence and Management of Reflex Sympathetic Dystrophy-Causalgia of the Extremities.
James W. Toumey, M.D.
The Use of Iliac Bone Grafts in Orthopaedic Surgery.
I. S. McReynolds, M.D.
Fractures of the Carpal Scaphoid.
H. Osmond Clarke, F.R.C.S. (London, England)
Delayed Bone Graft in the Treatment of Congenital Pseudarthrosis.
John R. Moore, M.D.
Short First Metatarsal—Its Incidence and Clinical Significance.
T. Beath, M.D.
R. I. Harris, M.B.

TUESDAY, JANUARY 27

Morning Session

Legg-Perthes Disease—A Method of Conservative Treatment.
Maurice M. Pike, M.D.
The Relationship between Congenital Subluxation and Congenital Dislocation of the Hip.
Vernon L. Hart, M.D.
Treatment of the "True" Congenital Luxation of the Hip. Results of the Open Reduction.
Professor Jacques Leveuf (Paris, France)
Symposium on Orthopaedic Rehabilitation—Frank Stinchfield, M.D., Chairman
Aspects of Physical Reconditioning.
Marcus J. Stewart, M.D.
Vocational Rehabilitation.
Michael J. Shortley, M.D.
Rehabilitation of the Severely Handicapped.
Henry H. Kessler, M.D.

Afternoon Session

Dupuytren's Contracture: A Report of Fourteen Cases of Combined Palmar and Plantar Lesions.
J. Vernon Luck, M.D.
The Problem of the Lumbar Intervertebral Disc—Some Pathological and Clinical Aspects.
Professor Sten Friberg (Stockholm, Sweden)

Criteria for Spine Fusion Following Removal of Protruded Nucleus Pulposus.
Guy A. Caldwell, M.D.
William B. Sheppard, M.D.
The Problem of the Primary Curve in Idiopathic Scoliosis.
John R. Cobb, M.D.
Changing Concepts in Scoliosis.
W. H. Von Lackum, M.D.

WEDNESDAY, JANUARY 28

Morning Session
Symposium on Treatment of Fractures of the Long Bones—Mather Cleveland, M.D., Chairman
The Use of Skeletal Traction in the Treatment of Fractures of the Femur.
Edward M. Winant, M.D.
Open Reduction and Internal Fixation of Long-Bone Fractures.
Harrison L. McLaughlin, M.D.
External Skeletal Fixation in the Treatment of Tibial Fractures.
John R. Naden, M.D.
Surgical Treatment of Non-Union of Long Bones.
Dr. Robert Merle D'Aubigne (Paris, France)
Presidential Address.
Rex L. Diveley, M.D.

Afternoon Session
The Cervical Syndrome as a Causative Factor in Certain Shoulder Disabilities.
Ruth Jackson, M.D.
Margaret Watkins, M.D.
Aseptic Necrosis of the Femoral Head.
Joseph M. Regan, M.D.
Ralph K. Ghormley, M.D.
Early Effects of Partial Denervation of the Hip for Relief of Pain in Chronic Arthritis of the Hip.
Benjamin E. Obletz, M.D.
Hamstring-Tendon Transplantation for the Relief of Quadriceps Paralysis in Residual Poliomyelitis.
J. R. Schwartzmann, M.D.
C. H. Crego, Jr., M.D.
Traumatic Proliferations of Fibrocartilage with Ossification in the Genesis of Spondylitis Deformans and Traumatic Myositis Ossificans.
Edwin F. Hirsch, M.D.

THURSDAY, JANUARY 29

Morning Session
The Status of Lumbosacral Fusion. An Operation of Transfacet Mortised Bone Block.
Earl D. McBride, M.D.
Arthrodesis of the Spine. An Ankylosing Method Permitting Early Ambulation.
Roger Anderson, M.D.
Ivan Loughlen, M.D.
Pen-Chien T'Ung, M.D.
The Flexion Block Fusion with Screw Fixation of Facets.
O. Anderson Engh, M.D.
Acute Anterior Dislocation of the Shoulder.
Toufick Nicola, M.D.
Posterior Dislocation of the Shoulder.
John C. Wilson, M.D.

The Annual Dinner will be held on Wednesday evening, and on Tuesday evening a stag smoker, which will give the members an opportunity to meet our distinguished foreign guests.

The American Society for Surgery of the Hand will meet in Chicago on January 23 and 24, in conjunction with The American Academy of Orthopaedic Surgeons. The preliminary program of the meeting was published in the October issue of *The Journal*.

A six-week course in **General Orthopaedic Surgery and Traumatology**, beginning on February 2, will be conducted by Dr. Arthur Steindler and associates at the College of Medical Evangelists, Los Angeles.

The National Society for Crippled Children and Adults, Inc. will hold its usual sale of East seals. These seals will be sent in letters from the State Societies, early in March. The gross return from tl sale of Easter seals in 1947 was one million dollars more than in the previous year. This money is used provide needed services to crippled children in forty-three states, and in Hawaii and Alaska.

An intensive **Postgraduate Course in Orthopaedic Surgery** will be given at the Medical Center and the San Francisco County Hospital February 9 through 13. The general chairman of the course is Dr. LeRoy C. Abbott, Professor of Orthopaedic Surgery, University of California Medical School. Requests for application should be addressed to Stacy R. Mettier, M.D., Head of Postgraduate Instruction, Medical Extension, University of California Medical Center, San Francisco 22, California.

Dr. Dallas B. Phemister of the Department of Surgery, University of Chicago, was awarded the Danis Prize on September 15, 1947, at the meeting of the International Surgical Society, held in London, because of his work on "Treatment of Ununited Fractures by Onlay Grafts without Screw or Tie Fixation". The fund for this prize was established by the pupils and friends of Robert Danis, for many years Professor of Surgery at the University of Brussels. The prize is awarded at the meeting of the International Surgical Society, which usually takes place every three years, and is given for the most important work on the operative treatment of fractures.

The second annual meeting of the **New Jersey Orthopaedic Society** was held at the Hospital and Home for Crippled Children, Newark, on October 11, 1947. The scientific program, arranged by Dr. Toufick Nicola and his committee, included the following papers:

Shelf Operation for Congenital Dislocation of the Hip—Harry Merliss, M.D. (by invitation)
Scoliosis: Rapid Method of Correction of Deformity Preliminary to Spine Fusion—Vincent Scudese, M.D. (by invitation)
Basile Operation for Flat Feet—H. Kunz, M.D. (by invitation)
Amputations in Europe—Henry H. Kessler, M.D.
Saucerization and Skin-Grafting for Chronic Osteomyelitis—J. J. Flanagan, M.D.
Bone Tumors in Children—E. Seifert, M.D. (by invitation)
Operative Results of Bone Cysts—Henry De Vincentis, M.D. (by invitation)
Osteoid Osteoma—R. R. Goldenberg, M.D.

The **U. S. Public Health Service Research Grants Program,** which has been in operation since 1946, is financed by public funds in the support of research, conducted without government control, by independent scientists. The purpose of these grants is to stimulate research in medical and allied fields by making funds available and by actively encouraging scientific investigation of specific problems on which scientists agree that urgently needed information is lacking. Since 1946, a total of $11,061,000 has been provided for the program, exclusive of appropriations for research grants in the fields of cancer and mental health. A total of sixteen grants, which represent an expenditure of $159,910, have been approved for research work in the field of surgery.

Late in 1945, the Research Grants Division was established to administer the grant program of the Public Health Service with Dr. C. J. Van Slyke as Chief. In July 1947, in order to effect coordination in the administration of the programs of research grants and research fellowships, the administration of the U. S. Public Health Service Fellowship Program was delegated to the Research Grants Division, which is now known as the Division of Research Grants and Fellowships.

Final recommendations to the Surgeon General of the Public Health Service are made by the National Advisory Health Council regarding all research grants, except those relating specifically to the fields of cancer and mental health, for which the National Advisory Cancer Council and the National Advisory Mental Health Council, respectively, are responsible.

At the request of the National Advisory Health Council, the fields of medical and allied research were classified into twenty major categories, and Special Study Sections, made up of consultant experts in these twenty fields, have been established. Late in 1946, the Surgery Study Section was organized with Dr. Frederick A. Coller, Professor of Surgery, University of Michigan School of Medicine, as Chairman.

Sixteen grants have been made for study in the field of surgery. Although most of the funds available for the fiscal year ending June 30, 1948, have been expended, the Public Health Service is encouraging investigators to present new applications in order to plan for next year's operation. Applications for new grants may be submitted at any time and should be addressed to: Chief, Division of Research Grants and Fellowships, National Institute of Health, Bethesda 14, Maryland.

Book Reviews

MEDICAL DISORDERS OF THE LOCOMOTOR SYSTEM INCLUDING THE RHEUMATIC DISEASES. Ernest Fletcher, M.A., M.D. (Cantab.), M.R.C.P. Edinburgh, E. and S. Livingstone, 45 shillings; Baltimore, The Williams and Wilkins Company, 1947. $11.00.

As the title implies, the object of this book is to bring together the available information on the medical disorders of an important system of the body, one which has tended to fall between the specialties of internal medicine and orthopaedic surgery. That this group of disorders should form an independent specialty, as advocated by the author, seems debatable; but further discussion on this point is beyond the province of this review. To accomplish this monumental task, Dr. Fletcher has been aided by the contributions of others well qualified to describe certain aspects of the subject. Among these, the chapter on "Applied Anatomy" by G. A. G. Mitchell stands out in clarity and conciseness, although the insertion of a larger number of illustrations and diagrams would be of aid to the reader. "Radiology" by F. C. Golding has been outlined only in respect to arthritis, but roentgenograms of other conditions have been adequately provided in the remainder of the book. W. S. C. Copeman has handled the subject of "Fibrositis" according to the prevailing British viewpoint, which is not accepted in entirety in this country. Other special contributions include "The Ear, Nose, and Throat" and "The Teeth as Sources of Focal Infection", "Medical Diseases of Bone", "Laboratory Findings in Rheumatism", and "The Incidence and Prevalence of Adult Rheumatism". The last, by a statistician, illustrates the inadequacy of available data, chiefly due to inherent difficulties in the diagnosis and classification of the rheumatic diseases.

The remainder of the book has been the responsibility of the author himself and is devoted to a systematic description of the wide variety of disorders affecting the locomotor system, with great emphasis and space necessarily given to the rheumatic disorders. In addition, there are separate chapters on the important and difficult subjects of "Sciatica", "Brachial Neuralgia", "The Shoulder Joint", and "Backache". The differential diagnosis of these conditions is presented in a helpful and informative fashion, as are, in general, methods of treatment. Topics omitted or inadequately treated for a work of this kind include lupus erythematosus disseminatus, dermatomyositis, scleroderma, amyloidosis, Dupuytren's contracture, and pigmented villonodular synovitis.

As stated in the Preface, this book is designed for the specialist in locomotor disorders. From this standpoint alone does the author seems justified in describing in detail a number of outmoded or unestablished methods of treatment, without definite statements of his opinion as to their value. The book can, therefore, be recommended unreservedly only to the critical reader with a wide experience in arthritis and allied conditions.

HOSPITAL CARE IN THE UNITED STATES. Commission on Hospital Care. New York, The Commonwealth Fund, 1947. $4.50.

The report of the Committee on the Cost of Medical Care in 1932 was the first comprehensive study of sickness, health, and hospitals in the United States. It considered the problem of sickness, and the extent and use of available treatment and preventive measures. It computed its cost to the patient and income to the doctor. The report presented the needs of the country in doctors and hospital beds, separating the cost of sickness into hospital costs, nursing costs, medicines, and professional fees. It clearly established the importance of hospitals in the medical structure.

Now, in 1947, this report of the Commission on Hospital Care further emphasizes the strategic position of the hospital by devoting its entire 600 pages to "A Study of the Function of the General Hospital, Its Role in the Care of All Types of Illness, and the Conduct of Activities Related to Patient Service, with Recommendations for its Extension and Integration for More Adequate Care of the American Public".

The Commission was composed of twenty-two persons, plus a study staff of nine, and eight technical advisers, assembled in 1944 by a Post-War Planning Committee appointed by the Trustees of the American Hospital Association. It was financed by The Commonwealth Fund, the W. K. Kellogg Foundation, and the National Foundation for Infantile Paralysis. Although its work antedated and was separate from the surveys authorized by the Hospital Survey and Construction Act, recently passed by Congress, its activities undoubtedly influenced the Congress and advanced surveys in the states. It is presented "to the American people as a guide to the future development of hospital care", and as such should commend itself to all serious students of medical and hospital problems.

One is somewhat overwhelmed by the 181 conclusions and recommendations presented in the second

chapter, until one realizes that herein are condensed in summary form the wide variety of subjects cover... in detail in the next 300 pages.

Section III lays a foundation of facts and information dealing with a diversity of subjects, includin factors that have influenced the growth of hospitals, such as religion and war; the growth of hospitals i the United States; the functions of a General Hospital; its relations with public health departments; standards of service; and financing.

The following sections, building upon this foundation, present new and original data under such titles as factors affecting the size and need of hospital facilities,—that is, population, vital indices, socio-economi conditions, geography, and transportation; the relation of bed-occupancy rate to size of hospital; the eff of urban or rural surroundings; and, finally, a formula for measuring the need of a community for hospit facilities by means of what they term the "bed-death ratio". This is evolved as follows:

It has been found that the public uses 250 days of general hospital care for each death occurring and correlated sickness cared for in a general hospital. Adjusting this on an annual basis (dividing 250 by 365 gives 0.685), we get 0.7 of a bed for each hospital death, or a bed-death ratio. This must be adjusted again to allow for a normal occupancy of 75 per cent., or 0.875 of a bed. The death rate in the nation is 10.6 per 1,000. The Commission assumed that one-half of these deaths might properly be expected to occur in hospitals, or 5.3. Consequently they computed 4.96 or 5 beds as the number of general hospital and allied special hospital beds per 1,000 population as the ultimate and ideal future need of the nation.

There are many methods of computing hospital-bed needs, but the Commission recommends this as the most reliable, pointing out that it is applicable under varying conditions of urban and rural areas, in low-income and high-income districts, and in other economic or population conditions; it expresses accurately the ratio of actual use, as well as the anticipated immediate needs, and can also be used to foretell futur needs.

For example, when hospital deaths are 4.0 per 1,000, occupied beds are 2.8 per 1,000 population. As hospital deaths increase, so should the number of beds available be increased up to the assumed maximum of 5 beds per 1,000 population.

These 300 pages are the heart of the report and represent the constructive work of the Commission. The final 200 pages present the best history of hospital development in the United States yet compiled, and one to which reference will be gratefully made for years to come. This is interesting and instructive reading.

The final chapter presents a useful listing of all the governmental departments and agencies with which hospital administrators have to deal.

In short, this is primarily a reference book of great value for the planning of hospital development, illustrated with well-explained charts and tables, graphically showing the wide variation of hospital facilities and services in the different states. A practical yardstick for measuring hospital-bed needs, in the bed-death ratio, and future development and expansion for both urban and rural communities are discussed intelligently. Finally, there is an interesting and instructive history of hospital development in the United States.

Reconstructive and Reparative Surgery. Hans May, M.D., F.A.C.S. Philadelphia, F. A. Davis Company, 1947. $15.00.

In this ambitious monograph, Dr. May has covered the field of reparative surgery in a very broad way. The general principles of reconstructive surgery, with special emphasis on plastic surgery, are well presented; and there is a splendid résumé of the newer thinking concerning wound healing and the treatment of burns, resulting from research during the last decade. In the chapters on surgery of regions, some procedures are discussed which are more commonly presented in orthopaedic writings or those of other surgical specialties. For example, several pages are devoted to acute arterial embolism and embolectomy; there is a lengthy discussion of reparative surgery of the large joints of the extremities, including the hip; and space is given to the operation of circumcision. The book suffers because this textbook approach to some of the multiple, specialized problems of reconstructive surgery limits the possibilities of detailed presentation.

To the readers who refer to this book because of an interest in special phases of reparative surgery, careful study of the text and illustrations will be very enlightening. The author draws upon his early experiences with Lexer in Germany, and he quotes intelligently from the literature both of this country and of Germany. This book will thus be enlightening and valuable as a source for comparison of the techniques and methods in the two countries. Also, the reader will be repeatedly impressed with the contributions of the German surgeons of the last century and the early decades of this century.

To orthopaedic surgeons, the section on the extremities will be interesting. The author draws from the writings of others, but usually adds a comment based on his own experience. In the section of illustrativ cases, a variety of methods of soft-tissue replacement of the extremities are demonstrated. The value of a familiarity with these methods is becoming increasingly apparent.

This monograph will be useful as a reference work on many phases of reconstructive surgery. The systematic and concise fashion in which the material is presented makes for easy reference. An extensive bibliography is included, which is well selected and general in its scope.

The Journal of
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PAINFUL SHOULDER

Observations on the Role of the Tendon of the Long Head of the Biceps Brachii in Its Causation *

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Lesions affecting the tendon of the long head of the biceps brachii are among the more frequent causes of pain and disability in the region of the shoulder joint. Observation and inquiry disclose that, in the majority of cases, common predetermining factors are responsible for the several pathological conditions encountered, an appreciation of which serves materially in problems of differential diagnosis and in the selection of rational procedures for the correction of dysfunction. Of these predetermining factors, the most significant are the presence of the "supratubercular ridge" of Meyer (described in 1928) and a preternaturally shallow bicipital or intertubercular sulcus which, with excessive function or as the outcome of trauma, results in a variety of lesions; these include acute or chronic peritendinitis, varying degrees of attrition and damage to the tendon, and its partial or complete dislocation. In addition, phylogenetic and functional considerations are important for an understanding of the high degree of vulnerability of this tendon,—a liability which man has had to assume in his compromise with Nature by the adoption of the erect posture

Prior to a discussion of matters of etiology, differential diagnosis, and treatment, it would perhaps be advisable to consider and discuss the brief reports of four cases which exemplify some of the conditions mentioned.

CASE 1 W F , a male, aged sixty, had fallen six months before and struck the flexed elbow of the right arm Three weeks later he had pain in the right shoulder, which radiated down the front of the arm The pain continued and the patient lost the ability to move his shoulder

Examination showed almost no motion in the shoulder joint Attempted passive motion was accompanied by severe pain Great tenderness was elicited by pressure over the bicipital groove Roentgenograms revealed no pathological changes, and the bicipital groove appeared to be of normal depth and configuration

At operation the biceps tendon was found to be markedly injected, all of its sheen was lost There were adhesions to the transverse humeral ligament and the groove, as well as to the deep aspect of the tendon of the pectoralis major When the shoulder was elevated, the portion of the tendon lying in the upper part of the groove was observed to become lax and to buckle, owing to its adherence to the transverse humeral ligament After the tendon had been freed in the bicipital groove, it could not be pulled upward The biceps tendon was, therefore, fixed in the groove and the portion above the transverse humeral ligament was resected The shoulder was then manipulated, and intra-articular adhesions were felt and heard to give After this a free range of motion was possible

Ten days after operation the patient was encouraged to carry the extremity through a full range of motion Eight weeks after operation complete and painless motion had been established, and the patient returned to work.

* Read at the Annual Meeting of The American Orthopaedic Association, Hot Springs, Virginia, June 27, 1947

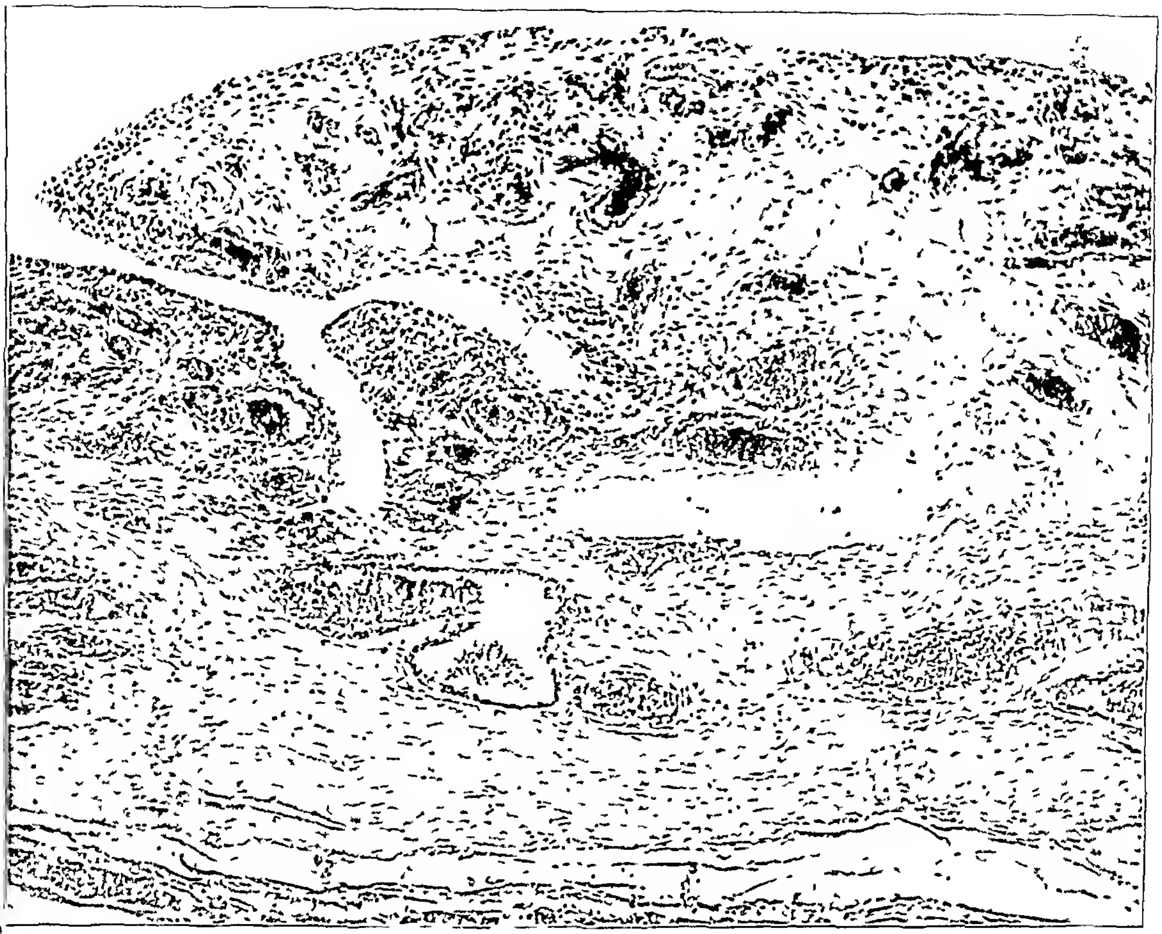

FIG. 1

Microscopic examination showed vascularization of the tendon and injection with lymphocytes and leukocytes (Fig. 1).

Operation disclosed adhesions, both within the joint and about the tendon of the long head of the biceps. Those adhesions involving the tendon interfered with the free play of the tendon within its groove, thus interrupting mechanically the function of the joint. Previous experience indicated that simple division of the adhesions about the tendon is inadequate, because of the rapidity of their reformation. Resection of the proximal portion of the tendon completely prohibits any possibility of interference of joint action by buckling of the tendon, and fixation of the distal portion in the line of its axial pull avoids the tissue distortion responsible for the recurrence of pain. Restoration of function and the loss of symptoms in this case were extremely rapid; the authors do not believe that such complete recovery could have taken place in the short space of eight weeks without operation.

Scapulohumeral periarthritis was described as early as 1872 by Duplay, who recorded the presence of adhesions within the subacromial bursa. The observations of this author were centered on the bursa to the neglect of a frequently accompanying peritendinitis, involving the long head of the biceps muscle. In consequence, he failed to appreciate the significance of pathological changes about this tendon in contributing to the disability. Since Duplay's report, greater consideration has been given to the effects of loss of the gliding space about the musculotendinous cuff in the production of the frozen shoulder than to the significant role of peritendinitis about the long head of the biceps muscle in producing a very large part of the functional difficulty.

In 1932, however, Pasteur recognized that peritendinitis affecting the long head was a cause of pain over the bicipital groove and was responsible for the limitation of motion at the shoulder joint. The reports of Meyer, Gilcreest, Schrager, Lippmann, Moseley, and Tarsy have made the nature of these lesions more widely known. Lippmann clearly demon-

trated the role of the tenosynovitis, by operation on thirty-two patients with frozen houlder. In two of these cases he drew attention to the presence of adhesions within the ubacromial bursa. On the other hand, Neviaser found capsular adhesions in ten such ases, but did not explore the tendon. Meyer has greatly extended our knowledge of the athology of the subject by drawing attention to the more advanced stages of attrition which accompany excessive functional use. With the exception of Meyer, none of these writers has been able to advance a satisfactory etiological explanation for his findings.

Case 2. In a male iron worker, twenty-five years old, acute burning pain developed in the right shoulder, ollowing a straight downward pull. Following this initial strain, an uncomfortable snapping could be reproduced by rotation of the humerus in a slightly abducted position. Firm pressure over the bicipital groove would prevent the snapping. The extremes of motion were painful, and there was tenderness over the bicipital groove. Roentgenograms showed a shallow bicipital groove in each shoulder. No other bone abnormality could be seen.

Because of the discomfort and snapping in his shoulder, an operation was performed eight weeks after he injury. No abnormalities of the tendinous cuff or subacromial bursa were found. As a result of a shallow groove with a very lax roof, the tendon of the long head of the biceps could become dislocated inward onto he lesser tuberosity.

After the lateral half of the floor of the bicipital groove had been lifted and the tendon beneath it had been sutured, the tendon of the long head of the biceps was fixed into the bicipital groove. The portion above the transverse humeral ligament was resected. The patient made an uneventful recovery and returned to work eight weeks after his operation.

It is significant that this man was operated upon shortly after his initial injury. The shallow bicipital groove was present in each shoulder and was a contributing cause to the dislocation of the biceps tendon; it was not a result of changes produced by his injury.

Abbott and Saunders have recognized both recurrent dislocations without trauma and acute traumatic dislocation of the tendon. In discussing the anatomical factors favoring these dislocations, they draw attention to the varying relationship of the tendon to the groove in different positions of the extremity. Béra, in 1910, stated that malformation or localized osteitis reduced the height of the lesser tuberosity and was of prime importance in the occurrence of dislocation of the tendon. A similar view was propounded by Horwitz, who observed fraying of the tendon in association with such bony changes. On the other hand, Meyer noted many examples of spontaneous dislocation of the tendon in the absence of arthritis or anatomical abnormality about the tubercles, which led him to conclude that dislocation and severance of the tendon constituted a common outcome of the everyday wear and tear of use. Among other factors, he drew special attention to the significance of the supratubercular ridge in facilitating dislocation, but made no observation on the variations in depth of the groove.

Case 3. V. M., a male, aged sixty-one, had wrenched his left arm two years before, while opening the turtleback of a car. He had severe pain in the front of his left upper arm at the time. This became less severe after the application of local heat, but sudden movements of the left shoulder caused severe pain in the shoulder. Finally the pain became continuous.

Examination showed pain with sudden movements of the shoulder, and tenderness over the bicipital groove. Anteroposterior roentgenograms revealed no bone abnormalities. Unfortunately, no films were taken to show the groove.

At operation the only pathological findings were about the biceps tendon. The bicipital groove was very flat. The tendon was dislocated inward from the bicipital groove, and was impaled on a sharp bony spur which projected from the lesser tuberosity. With movement of the shoulder, this spur frayed the tendon. The tendon was more than half cut through by it. There was a very loose fibrous sling about the tendon, which permitted it to lie in the abnormal position in which it was found.

The biceps tendon was fixed in the bicipital groove. The portion above the groove was resected, and the spur on the lesser tuberosity was removed with an osteotome.

The patient made an uneventful recovery and returned to work, with a full range of painless motion, eight weeks after the operation.

Case 4. Nine months before, J. R. had fallen five feet and had struck on the point of the flexed left elbow Following this he was unable to raise his left arm. Attempts to move the shoulder passively were painful There was tenderness to pressure over the bicipital groove. Roentgenograms were negative

At operation it was found that the long head of the biceps tendon had been dislocated inward over the lesser tuberosity from a normal-appearing groove. There was no fascial sling about the tendon, such as is seen with a recurrently dislocating tendon and shallow groove. There was an exostosis over the greater tuberosity, and adhesions between this and the deltoid muscle. The tendon was fixed in the groove, and the portion proximal to the transverse humeral ligament was resected. The exostosis and adhesions were resected. No further joint adhesions were felt to give when the arm was put through a full range of motion. Motion was begun ten days after operation. A full range of painless motion was possible in six weeks.

This represents a forceful dislocation of the long head of the biceps tendon, with trauma and adhesions to the greater tuberosity of the humerus.

ANATOMICAL OBSERVATIONS

In order to determine the incidence of the supratubercular ridge and variations in the depth of the intertubercular groove, as well as their significance in producing lesions involving the biceps tendon, 100 humeri were examined.

The Supratubercular Ridge of Meyer

The supratubercular ridge is a ridge of bone, projecting immediately proximal to the medial wall of the bicipital groove and continuous with it. The biceps tendon is limited by this structure from slipping inward and is forced upward against the transverse humeral ligament, thus favoring dislocation. Meyer reported that, in an unpublished study made by Cilley, this ridge was present in 17.5 per cent. of 200 humeri. In the present series it was found to be markedly developed in 8 per cent. of the humeri and moderately developed in 59 per cent. (Fig. 2). The relatively greater incidence in this series is accounted for by the fact that Meyer's report included only those meeting an exact anatomical configuration. We have, however, included all ridges which we judged were high enough to force the biceps tendon against the roof of the groove and thus cause trauma to the tendon. The fact that pressure against the fibrous roof and inflammatory changes have actually occurred from its presence is proved by the finding of a spur on the lesser tuberosity in 45 per cent. of the humeri of our series which showed a supratubercular ridge. On the other hand, in the absence of a supratubercular ridge, in only 3 per cent. of the humeri were spurs demonstrable on the lesser tuberosity (Fig. 2). Humeri showing any other hypertrophic changes are excluded from these percentages.

Variations in the Depth of the Groove

A marked variation in the depth of the bicipital groove exists, which is most conveniently expressed as the angle of the medial wall of the groove (Fig. 3). In 8 per cent. of the humeri, the medial walls of the groove made an angle of less than 45 degrees; this establishes a close correlation with Meyer's finding that 8 per cent. of biceps tendons were dislocated in a fascial sling from a shallow groove.

Comparative Anatomy of the Biceps Groove

Man is unique among the Primates in presenting marked variations in the conformation of the bicipital groove. The angle of the medial wall is identical in all specimens in the gorilla (22), chimpanzee (38), gibbon (28), and orangutan (18). The orangutan, which is an active climber, has the shallowest groove, with a medial-wall angle of 60 degrees. Supratubercular ridges are common in all of these species (Fig. 3).

Functional Anatomy

Contrary to what is often superficially thought, it is not the tendon which slides in the groove, but the humerus which moves on the fixed tendon during motions at the shoulder. From adduction to complete elevation of the arm, a given point in the groove moves along the tendon for a distance of at least one and one-half inches. In order to facilitate such motion, a synovial pouch extends from the shoulder joint to line the intertubercular groove

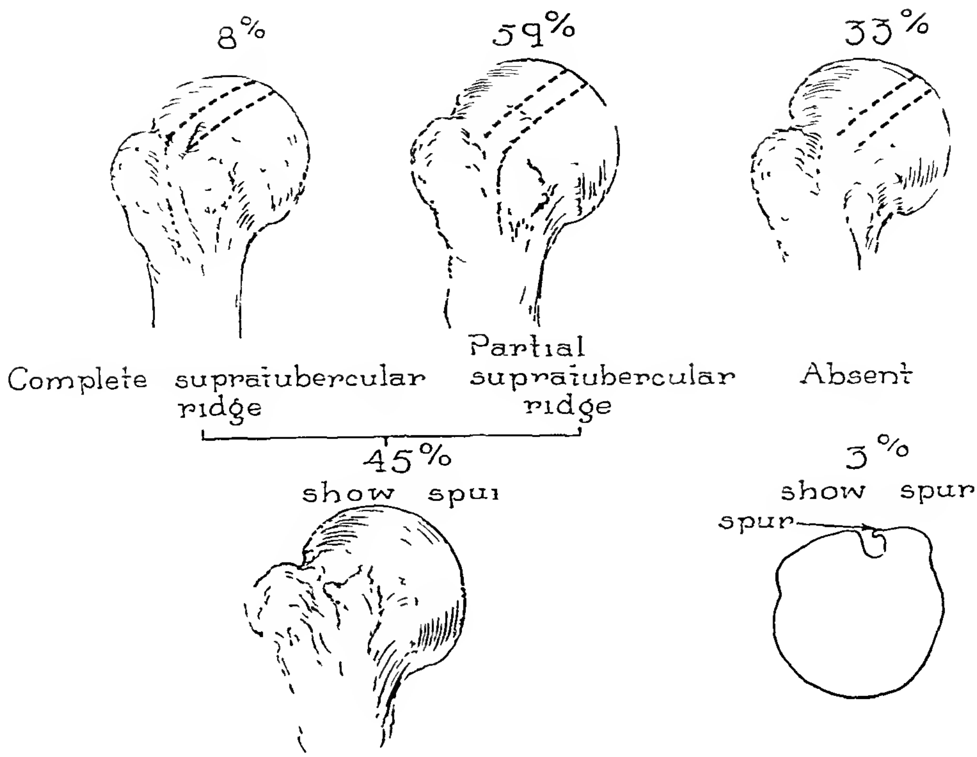
8%
59%
33%
Complete supratubercular ridge
Partial supratubercular ridge
Absent
45%
show spur
3%
show spur
spur

Fig 2

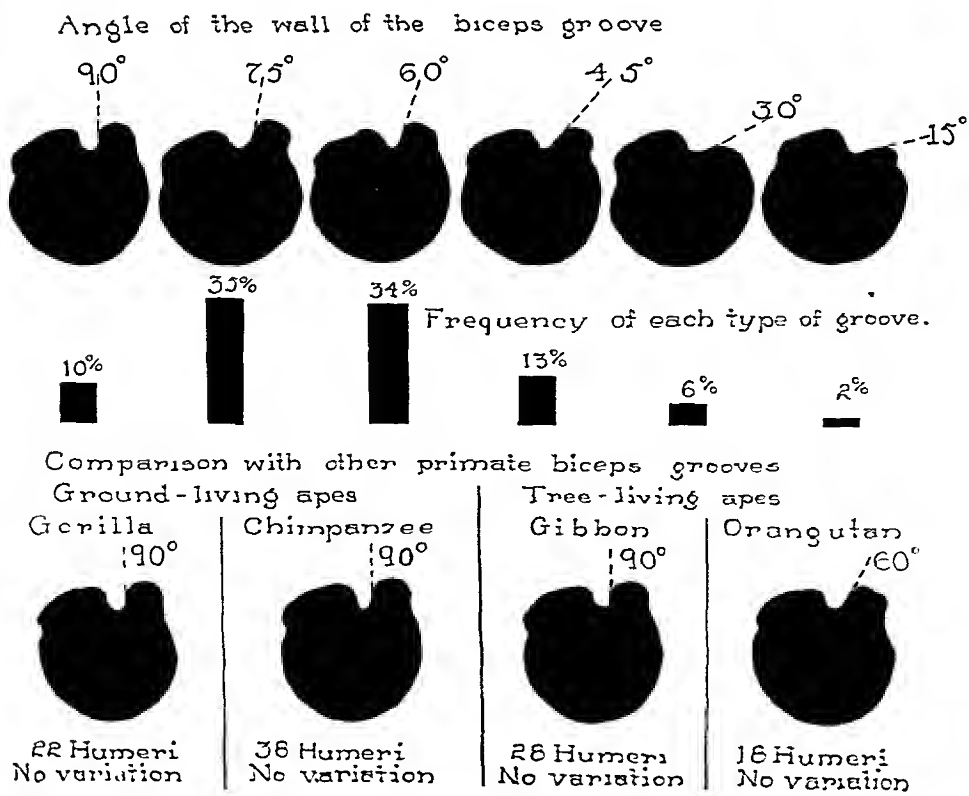
Angle of the wall of the biceps groove
90°
75°
60°
45°
30°
15°
10%
35%
34%
13%
6%
2%
Frequency of each type of groove.
Comparison with other primate biceps grooves
Ground-living apes
Tree-living apes
Gorilla
90°
22 Humeri
No variation
Chimpanzee
90°
36 Humeri
No variation
Gibbon
90°
26 Humeri
No variation
Orangutan
60°
16 Humeri
No variation

Fig. 3

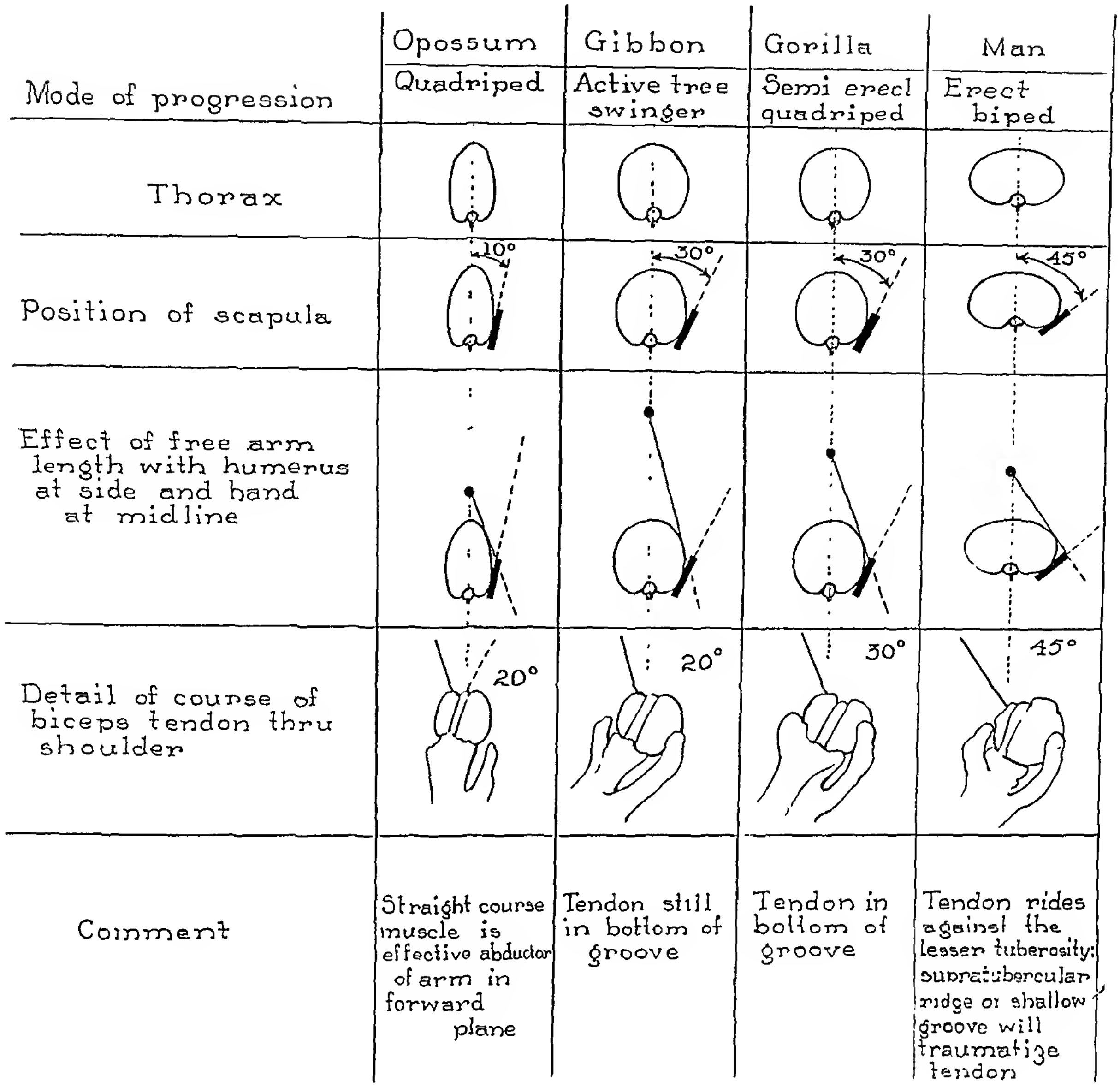

FIG. 4

for the greater part of its extent. Below this bursa, the tendon glides through its peritendineum.

Motion of the humerus on the tendon occurs in all movements of elevation at the shoulder, whether elevation be accomplished through the pathway of forward flexion or abduction. As these movements are nearly always associated with strong flexion and supination at the elbow, the long head of the biceps is rendered exceedingly taut. If, at the same time, the arm is medially rotated at the shoulder, the tendon plays on the medial wall of its groove and the lesser tubercle acts as a trochlea or pulley. On the other hand, when the arm is in full lateral rotation, the tendon occupies the floor of the groove, and its more proximal portion exercises pressure on the head of the humerus. Therefore, it is in lateral rotation only that the long head acts directly on the shoulder joint and enhances somewhat the power of abduction at this joint.

The Role of Oedema or Adhesions in Causing Pain

If, during motion, the tendon of the long head of the biceps is involved by adhesions, not only is the upward thrust of the humerus hindered, with consequent limitation of motion, but the pull is transferred to the adhesions and through them to the very sensitive surrounding tissues, such as the periosteum and fasciae. The pain is due in large measure to the effects of stretching the surrounding adhesions.

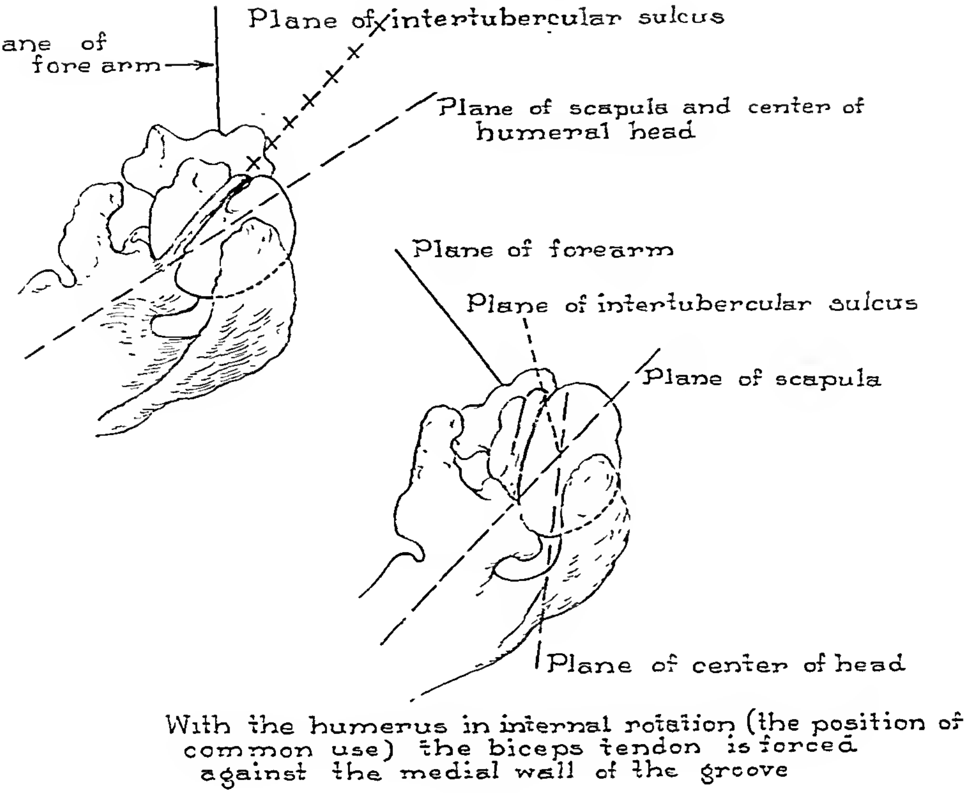

FIG. 5

Anatomical Factors Responsible for Vulnerability of the Tendon

Neither the supratubercular ridge nor a shallow bicipital groove can cause injury to the biceps tendon, unless the tendon is forced against the lesser tubercle and medial wall of the groove. As has been pointed out, the tendon is commonly brought into relationship with this wall, as we habitually use the extremity in various degrees of medial rotation during elevation. A number of phylogenetic factors have been responsible in man for the gradual displacement of the tendon in the medial direction (Fig. 4). These factors are:

1. Anteroposterior flattening of the thorax, which leads to dorsal rotation of the scapula and lateral displacement of the glenohumeral joint.

2. A relatively short forearm which necessitates greater medial rotation of the humerus in order that the hand may reach the mid-line.

3. The anteroposterior flattening of the thorax and the short forearm are compensated for, but only incompletely, by torsion of the humerus and migration of the bicipital groove (Fig. 5).

Man has been unable to adapt himself fully to the requirements of an erect posture. Changes in thoracic shape necessitate the lateral position of the shoulder girdle, but functional demands of a prehensile extremity require its use in relationship to the ventral aspect of the body, thus establishing another example of conflict between function and structure. In the pronograde, the tendon of the long head of the biceps plays over the center of the hemispherical head of the humerus, to pass directly into its groove which lies in the same plane. The tendon is thus secure and remains a powerful force in elevation. In the orthograde, on the other hand, lateral migration of the shoulder girdle has, so to speak, left the tendon behind on the ventral aspect, in order that the muscle may continue to serve the function of the forearm. As a consequence, the groove no longer lies in the same plane as the center of the head, but makes an angle, according to Saunders and Inman, of

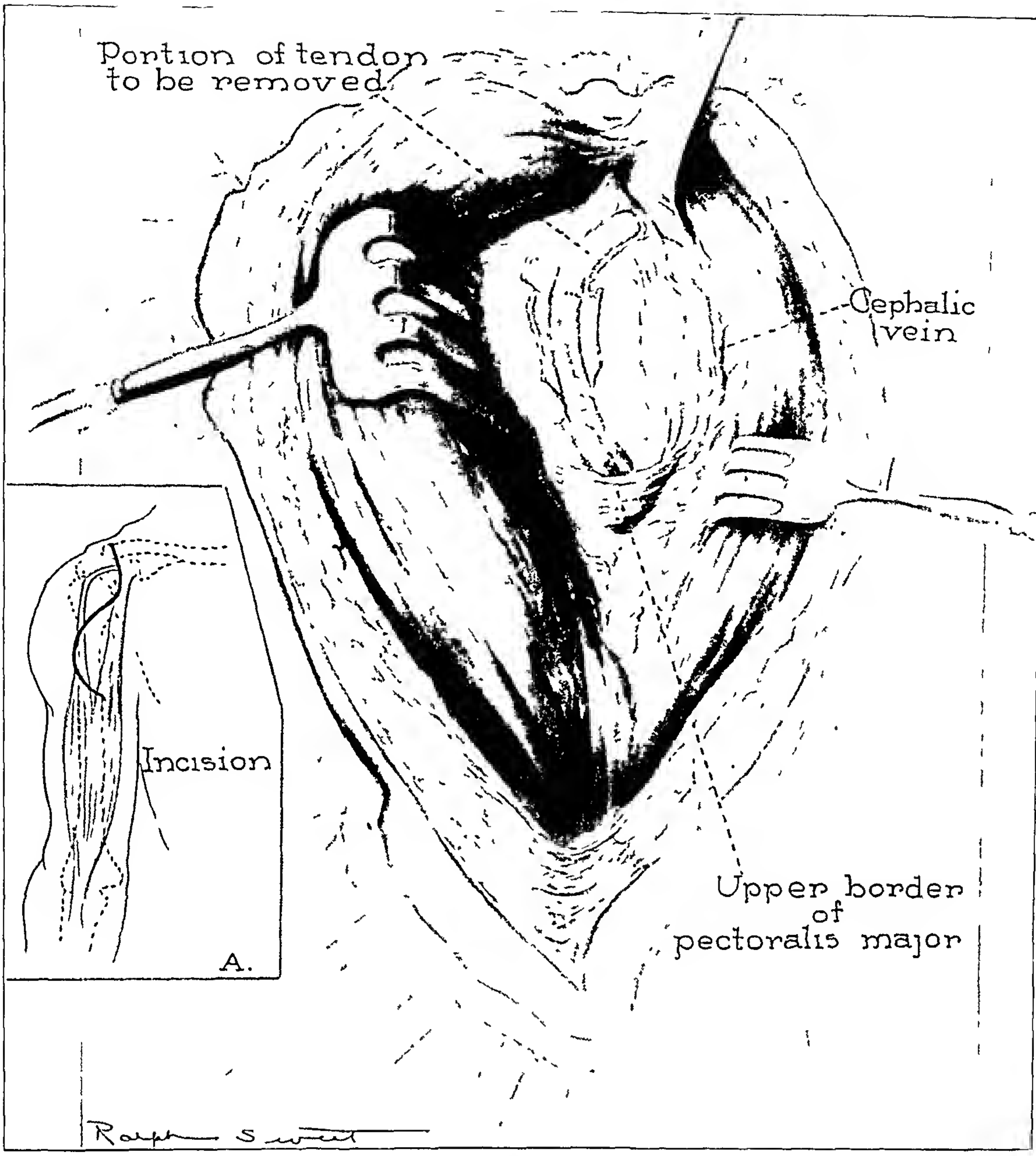

FIG. 6

30 degrees to it. The tendon now occupies a very insecure position which is compensated for, but very incompletely, by torsion of the humerus. Medial rotation of the humerus, to permit the hand to be brought to the position of function at the mid-line, further exaggerates the displacement of the tendon, which is forced to bear on the lesser tubercle and medial wall of its groove. Such a relationship renders the tendon in this region highly vulnerable, not only to the trauma of a single severe incident, but also to that of everyday function. A supratubercular ridge and a shallow groove enhance the likelihood of injury.

Relative Position of the Humerus in Various Mammals

In Figure 4 the relative shape of the thorax and the relative position of the scapula are shown for the opossum, the gibbon, the gorilla, and man. After a review of these, it might be argued that all the humeri have been placed in the human position, and that the various species make greatest use of their arms in other positions. This serves merely to emphasize the point that man habitually holds his humerus in abduction and internal rotation. Thus, in addition to having a poor anatomical arrangement, man's arm is held and used in a position which produces the greatest wear on the biceps tendon and makes dislocation more likely.

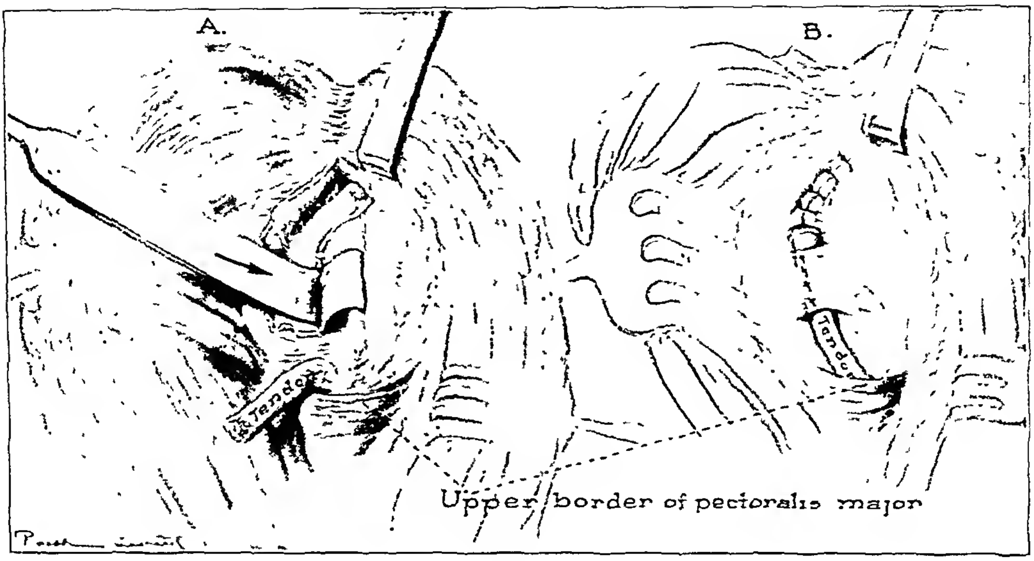

Fig. 7

DIAGNOSIS

In the presence of a lesion affecting the long head of the biceps muscle, the most constant physical finding is tenderness over the tendon. Tenderness may be found anywhere from the level of the tubercles and distally along the course of the tendon, or over the insertion of the pectoralis major, to the lateral lip of the intertubercular ridge.

Dislocation of the tendon, complete or incomplete, may be differentiated from a peritendinitis by the test of Abbott and Saunders. After full abduction of the shoulder, the arm, which is held in complete lateral rotation, is slowly brought down to the side in the plane of the scapula. A palpable or even audible, and sometimes painful, click is noted as the biceps tendon, now forced against the lesser tubercle, becomes dislocated from the groove.

Roentgenograms are, unfortunately, of little value, except for the purpose of excluding other types of lesions affecting the shoulder region. However, shallowness of the groove or the existence of a spur on the lesser tuberosity may be demonstrated in axial views. A supratubercular ridge can readily be seen in the usual anteroposterior films taken with the arm in external rotation; this provides presumptive evidence, in the presence of pain and tenderness over the groove, of possible damage to the tendon.

With a frozen, painful shoulder, failure of the condition to clear up quickly with manipulation and physical therapy, together with persistent tenderness over the intertubercular groove, very probably means inflammation and adhesions about the biceps tendon. It should not be forgotten that peritendinitis of the long head may be associated with other lesions about the shoulder, such as rupture of the tendon of the supraspinatus. In consequence, the peritendinitis may be overlooked, with resultant disappointment in the results of therapy.

TREATMENT

Manipulation under an anaesthetic, followed by balanced traction, has been used for the painful frozen shoulder. Where tenderness over the bicipital groove has been present, convalescence has usually been long and difficult. Fixation of the long head of the biceps tendon to the floor of the intertubercular groove, in the manner to be described, greatly expedites convalescence and promotes loss of pain and rapid functional recovery.

Where recurrent or traumatic dislocation of the biceps tendon is found, surgery is indicated.

Operative Procedure

An S-shaped skin incision over the deltoid-pectoral interval (Fig. 6) serves to lessen the tendency to hypertrophied scar, which is common when a straight incision is employed.

Careful observation and exploration of the tendinous cuff and the subacromial bursa should always be made.

Adhesions and peritendinitis of the biceps tendon are usually not seen until the tendon has been exposed by incision of the capsule and transverse humeral ligament; the tendon may then be visualized from its origin as far as its point of disappearance beneath the tendon of the pectoralis major. After exposure of the tendon, abduction of the arm will demonstrate whether the humerus slides freely along the tendon or whether it is bound by adhesions under the tendon of the pectoralis major. If such adhesions are present, the terminal portion of the tendon will buckle with abduction.

With an osteotome, a bed is made in the groove by elevating a portion of the floor from the outside inward. The tendon is roughened, and is sutured beneath this osteoperiosteal flap with heavy silk sutures (Fig. 7). The transverse humeral ligament is sewed down over the tendon and osteoperiosteal flap. The portion of the tendon lying above the transverse humeral ligament is resected. The shoulder is then put through a full range of motion. Very often, adhesions in the joint will be felt and heard to give. The wound is then closed without muscle sutures.

Objections to Other Sites of Fixation of the Tendon

Fixation to the short head of the biceps changes the course of the tendon and may produce pain, due to pulling on adhesions to the tendon under the pectoralis major insertion.

Fixation to either tuberosity of the humerus produces a prominence which will cause pain by abutting against the coraco-acromial ligament during elevation of the shoulder.

Fixation to the pectoralis major tendon produces pain by cross pull on that tendon.

Postoperative Care

The shoulder is kept in a Velpeau dressing for ten days; the stitches are then removed and the arm is put through a full range of motion, three times each week. Care is taken to avoid strain on the long head of the biceps tendon. At the end of six weeks the tendon should be well healed in its groove. The authors' experience in the treatment of lesions of the long head of the biceps muscle, according to the manner outlined, has been most gratifying. Loss of pain and the rapid return of function have been characteristic. The only residual disability is a slight loss in the power of abduction when the arm is in lateral rotation,—a loss which is scarcely appreciable to the patient and causes little inconvenience.

CONCLUSIONS

1. Lesions of the biceps tendon may be a cause of painful shoulder.
2. The normal anatomical mechanics of the biceps tendon are faulty. A supratubercular ridge or flat bicipital groove increases the mechanical difficulties.
3. An operation to fix the tendon in the bicipital groove and to remove that portion of the tendon above the groove relieves the symptoms caused by it and does not materially weaken the shoulder.

NOTE: The authors wish to thank Dr. John B. deC. M. Saunders, Professor of Anatomy at the University of California Medical School, for his help and advice, and for permission to study the humeri of the skeletons in the Anatomy Department of the University of California. Thanks are also due to the Department of Osteology at The Chicago Natural History Museum, for permitting a study of their primate humeri.

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DISCUSSION

Dr. J. Albert Key, St. Louis, Missouri: This is a very interesting exposition of the anatomy and pathology of the long head of the biceps. I see shoulders with pain and tenderness over the biceps tendon and bicipital groove and treat them conservatively as bursitis, unless the condition is very acute or calcium accumulations are present. In such cases we remove most of the calcium, and expect relief. I believe that some of my failures, especially in the cases of longer duration, are due to neglect of the biceps tendon.

In the future I shall examine this tendon when I operate upon a frozen shoulder, shall perform the procedure outlined in this paper, and believe that my results will be better. However, in some of these frozen shoulders, the entire joint is involved. In two cases which I inspected after manipulation, the inferior portion of the capsule was torn either across or away from the glenoid. Apparently this does not do any great harm. The shoulder has great regenerative powers, as anyone knows who has treated conservatively the so-called tears of the supraspinatus. I have not sutured a supraspinatus tendon in twelve years, and I do not think I have had a shoulder that has been permanently disabled because I failed to suture the supraspinatus. Most of them get well in a few weeks if we leave them alone. As to the biceps tendon, I have not found a case that I could diagnose as slipping of the biceps, and consequently I have not operated. I believe that this paper will help me to diagnose the cases of painful tenosynovitis of the long head of the biceps which I have treated as chronic subdeltoid bursitis.

Dr. Robert W. Johnson, Baltimore, Maryland: I want to compliment the authors on the presentation they have given of a lesion which I must have overlooked. I am not familiar with it. I wish Dr. Bennett were here, because he has had considerable experience with ballplayers, in whom tendon lesions of the shoulder are common. The biceps tendinitis is another pathological entity. As pointed out, it should not be confused with supraspinatus tears or bursal injuries. From this report, the operative procedure seems to be simple.

Since four cases were presented, I would like to ask the authors whether these four comprise their series, or whether these cases were selected to bring out a point. I think they selected four cases which differ from one another, in order to give us some idea of the picture.

Dr. Charles O. Bechtol (closing): It is true that most painful shoulders recover if given enough time. However, we feel that, in those cases of biceps peritendinitis where the patients do not recover promptly after conservative treatment, a much more rapid recovery with less economic loss can be offered by fastening the tendon into the groove. Our results in twenty-six such cases have been most satisfactory.

CONGENITAL PSEUDARTHROSIS

Follow-up Study after Massive Bone-Grafting *

BY HAROLD B. BOYD, M.D., AND KERMIT W. FOX, M.D., MEMPHIS, TENNESSEE

From the Campbell Clinic, Memphis

In 1941, a report was made as to the treatment of congenital pseudarthrosis by massive grafts, and a technique of dual bone-grafting was described [1]. It is the purpose of this paper to present a follow-up study of the cases reported at that time, and to add three additional cases of congenital pseudarthrosis of the tibia, treated with dual bone grafts.

In the 1941 report, bony union occurred in each patient who was treated with a massive bone graft. This resulted in an initial optimism which the subsequent findings do not substantiate. It has been found that refracture is prone to occur after bony union and that, when such a refracture does occur, the fracture site quickly reverts to a condition similar to that seen in the original pseudarthrosis. Union following a refracture is apparently as difficult to obtain as in the original non-union, with the exception that the patient is older and it is the consensus that, the older the child, the better the prognosis. The cause of the rapid absorption of bone about the fracture site following refracture is not known. In the patients reoperated upon for fractures following union, the tissue has been carefully examined for neurofibromata and none have been found.

In one of the case reports to be presented here, an "insufficiency" or so-called "march fracture" developed gradually at the original site of non-union, several years after bony union had occurred. The gradually developing "fracture" differed from a march fracture in that no callus developed about the fracture site. The insufficiency fracture weakened the bone to the extent that a minor trauma, even while the patient was wearing a brace, produced a complete fracture of the tibia.

Since refracture is prevalent, it is essential that adequate bracing be carried out following the bone graft until a new, well-developed medullary canal has formed across the fracture site, and until the tibia has reached sufficient size and strength to compare favorably with the normal one. This will usually require the use of a brace until the child is past puberty, which in actual practice means a period of from five to twelve years. It is the authors' opinion that the surgeon should watch for evidence of an early march fracture, recurrent sclerosis about the old fracture site, or narrowing of a previously reformed medullary canal. In the presence of one of these findings, or a combination, an operation to reinforce the area of former pseudarthrosis with supplementary grafts may be indicated before complete refracture of the tibia has had time to occur. This has not been done in any of our cases, but we believe that it may be an advisable procedure.

The first four case reports bring the original cases, reported in 1941, up to date. The last three cases are new.

CASE REPORTS

Case 1 (Campbell Clinic No. 15366). S. A., a white girl, was first seen on July 6, 1925, at the age of twenty-seven months. Anterior bowing of the leg was noticed during infancy, and fracture of the right tibia was first discovered at the age of fifteen months. The patient was placed in a cast for four weeks and in a brace for six months. The anterior and lateral bowing of the lower half of the tibia and fibula gradually increased. On admission, pseudarthrosis was demonstrated clinically and roentgenographically (Fig. 1-A). In addition to the pseudarthrosis of the tibia, a defect in the fibula was present. The history and roentgenographic findings indicated that the pseudarthrosis was probably secondary to a bone cyst.

* Read at the Annual Meeting of The American Orthopaedic Association, Hot Springs, Virginia, June 29, 1947.

Fig. 1-A

Fig. 1-B

Fig. 1-C

Fig. 1-A: Appearance of congenital pseudarthrosis before operation in a girl, twenty-seven months old.
Fig. 1-B: Appearance of the graft, one month and eleven days after operation.
Fig. 1-C: Appearance of the tibia, one year and three months after operation. Note that a small medullary canal has been re-established.
Fig. 1-D: Appearance of the tibia and fibula, twenty-two years after operation.

Fig. 1-D

On July 10, 1925, a massive onlay bone graft was done by Dr. Willis C. Campbell, who used a tibial graft from the mother. Circular wire loops were used to fix the transplant to the tibia. Cancellous bone was packed about the fracture site.

Roentgenograms, taken on August 21, showed the bone graft in place (Fig. 1-B). More than a year later, on October 9, 1926, roentgenograms (Fig. 1-C) showed solid union, with a medullary canal being re-established.

Valgus of 30 degrees of the right ankle and 25 degrees of the left ankle was present on May 20, 1937 (the valgus of the left ankle was due to congenital pseudarthrosis in the lower end of the left fibula). A supramalleolar osteotomy, to correct the valgus of the right ankle, was carried out on February 22, 1938. A similar operation was done on September 27, 1938, to correct the valgus deformity of the left ankle. Both osteotomies healed normally.

The patient was last seen on March 25, 1947, twenty-two years after the bone-grafting. She had no complaints relative to the pseudarthrosis. Figure 1-D shows the condition of the tibia on this date. Both legs were of equal length. There was approximately 20 degrees of valgus in both ankles, multiple café-au-lait spots, and two small subcutaneous masses, probably neurofibromata. The patient is a graduate nurse, she is married, has a child, and is doing her own housework.

Case 2 (Campbell Clinic No. 41036). H. L., a white boy, was first seen on May 25, 1937, at the age of two and one-half years. False motion and angulation of the lower third of the right tibia and fibula were present at birth. One operation for correction of the deformity had been done at the age of nine months. On admission, there was anterior bowing of the leg, with free motion at the fracture site. Many café-au-lait spots were present. Roentgenograms showed pseudarthrosis of the tibia and fibula, with tapering ends and overriding of the bone fragments.

On June 21, 1937, the tendo achillis was lengthened and Hallock's operation [2] was performed. The multiple chips used were obtained from the ilium of the mother.

A year later, on July 25, 1938, roentgenograms showed absorption of chip grafts. Clinically, motion was present at the site of the pseudarthrosis.

A massive onlay graft was done on March 2, 1939, tibial bone from the mother was used, and cancellous bone was packed about the fracture site. Roentgenograms, taken on November 18, 1939, revealed bony

union at the fracture site, but there was still a tendency toward hemi-hourglass constriction, and the medullary canal had not reformed.

On September 26, 1940, roentgenograms showed evidence of a reforming medullary canal. A constriction was present at the fracture site. There was one inch of shortening of the affected extremity. On May 24, 1944, roentgenograms showed an apparent slight increase in sclerosis and narrowing of the medullary canal in the region of the old fracture site.

On October 24, 1944, the boy fell from a merry-go-round and sustained a fracture of the tibia at the original site of the congenital pseudarthrosis. For the previous two and one-half years, against medical advice, the patient had walked, run, and played without using a brace.

Roentgenograms, two and one-half months after refracture (January 16, 1945) showed definite absorption of the bone ends, despite continuous immobilization in a cast.

A dual bone graft was performed on June 4, 1945, by Dr. R. A. Knight, the opposite tibia being used as a donor site. Incomplete union was present on February 18, 1946.

By March 12, 1947, there was only one-quarter of an inch of shortening of the affected extremity. However, actual tibial shortening was three-quarters of an inch; a longer femur compensated for some of the tibial shortening. The boy was still wearing a brace. Roentgenograms showed solid bony union.

Case 3 (Campbell Clinic No. 46921). W. J. W., a white girl, was first seen on July 19, 1939, at the age of five years. Fracture in the middle third of the left tibia had been present at birth. A bone graft, the fibula from the other leg being used, had been done at the age of one year. This was followed by cast immobilization for three years. On admission, there was anterior and medial bowing of the tibia and definite non-union, both clinically and roentgenographically. The left lower extremity was three-eighths of an inch shorter than the right.

Three days later, on July 22, dual bone grafts were applied, tibial bone from the father being used. Cancellous bone was packed about the fracture site and between the grafts. The screws were removed on December 27, 1940. Fifteen degrees of valgus of the ankle was present. The affected leg was three-eighths of an inch longer than the normal one. Roentgenograms showed bony union.

The patient was transferred from the authors' care. However, roentgenograms, taken elsewhere on October 3, 1941, showed union, but the tibia was still slender.

On February 20, 1942, roentgenograms, taken elsewhere, showed bony union with re-establishment of the medullary canal. The bone gradually became hypertrophied with use, but the tibia was still slender. This patient has moved to another section of the country and efforts to trace her since 1942 have failed.

Case 4 (Campbell Clinic No. 35657). R. L. D., a white boy, was first seen on March 25, 1935, at the age of three years. From the history, it was learned that the lower extremities had been apparently normal at birth. As the child grew, his parents noted a gradual anterior and lateral bowing of the left tibia. With increase in the deformity, a limp developed.

Four days before admission, while walking, the patient turned his ankle and noticed immediate pain in the lower third of the leg. After this, he refused to bear weight on the limb. Roentgenograms revealed a fracture at the juncture of the middle and lower thirds of the tibia, through a bone cyst. A large cystic area was also evident in the upper third of the tibia.

For the next four years, the leg was intermittently immobilized in plaster and supported by a brace, but non-union persisted. Roentgenograms, taken on September 20, 1939, showed a minimal amount of callus at the fracture site, with a marked increase in anterior tibial angulation. The bone cyst in the upper third of the tibia was decreasing markedly in size (Fig. 2-A).

A dual onlay bone graft was applied on September 23, 1939, tibial grafts from the mother being used. Roentgenograms, taken on January 26, 1940, showed beginning union of the grafts and obliteration of the fracture site. The alignment was satisfactory (Fig. 2-B).

By August 14, 1940, the leg was clinically solid. It had been immobilized in a cast for six months after operation and then supported by a brace. Roentgenograms showed that the screws had been removed; good bony alignment was present; the fracture line had been obliterated; and a good medullary canal had reappeared. The affected leg was one-half inch longer than the normal one.

The patient wore a brace for three years after operation. When seen on July 14, 1943, the foot on the affected leg was one inch shorter than the foot on the sound side. Roentgenograms disclosed no changes, except that the cyst had nearly disappeared.

When last seen on January 22, 1947, seven years and four months after the dual bone-grafting, the patient was carrying out normal activities for his age; the affected lower extremity was three-fourths of an inch longer than the sound one. A calcaneovalgus deformity of the left foot was present, associated with moderate cavus. Café-au-lait spots were noted on the abdomen and buttocks. Roentgenograms showed a sound tibia (Fig. 2-C).

Case 5 (Campbell Clinic No. 41224). J. E., a white boy, struck his left leg against a table and presumably sustained a fracture at thirteen months of age. However, the leg was thought to have been "crooked" before the fracture. The limb was immobilized in a cast for eight months, after which braces were used. He

is first brought to the Clinic for treatment at the age of five years. At this time the pseudarthrosis was still esent and roentgenograms (Fig. 3-A) showed the non-union with marked narrowing and overriding of the ne ends.

On September 15, 1941, a dual bone graft was applied, tibial bone from the foster father being used. gure 3-B showed the dual graft, three weeks after the operation. Cast immobilization was continued for e and one-half months, after which a brace was used.

By December 1, 1941, the leg was clinically solid. Weight-bearing in the brace was started on March 21, 42. Roentgenograms showed obliteration of the fracture line and union of the grafts to both tibial fragents, particularly the proximal one. On July 2, 1942, the screws were removed. Roentgenograms (Fig. 3-C) owed complete union of the dual grafts to the tibial fragments, and obliteration of the fracture line. Modere anterior angulation was present.

Roentgenograms, taken on August 26, 1943, showed a fairly well-developed medullary canal. The nterior bowing and ankle valgus had increased somewhat. The affected extremity was three-quarters of an ch shorter than the normal, but the femur on the affected side was longer.

When seen on July 28, 1944, the patient was continuing normal activities in a brace, without difficulty. oentgenograms continued to show a good medullary canal (Fig. 3-D).

Serial roentgenograms, beginning on February 10, 1945, showed the progressive development of an insufficiency" type of fracture, without callus formation about the advancing osseous defect (Figs. 3-E rough 3-I). An associated sclerosis of the bone appeared about the site of the former pseudarthrosis, with adual filling in and narrowing of the medullary canal. A complete fracture occurred as the result of a misep, while the patient was going down steps on August 14, 1946, approximately five years after the bonerafting (Fig. 3-J). He was wearing a brace at the time the fracture occurred.

A below-the-knee amputation was performed on September 2, 1946. At that time the affected tibia was ne and one-half inches shorter than the sound one. Roentgenograms of the specimen (Fig. 3-K) showed arked absorption of bone about the fracture site; this developed in a period of nineteen days, during which e leg was immobilized in plaster. At the present time, the patient is walking well with a prosthesis.

Case 6 (Campbell Clinic No. 58879). R. K., a white boy, was first seen on March 2, 1943, at the age of even and one-half years. Anterior bowing of the right leg had been noted at birth. A roentgenogram, taken on November 20, 1935, showed increased tibial and fibular bowing: the diameters of the bones remained normal.

Roentgenograms on April 27, 1936, showed a completely fractured fibula with absorption of bone ends, decrease in the medullary canal of the tibia, and increasing sclerosis.

On February 12, 1937, roentgenograms revealed complete obliteraion of the medullary canal in the tibia, with increased sclerosis at he site of angulation. Casts were used for intermittent immobilization rom the age of eight months until two years, at which time a corective osteotomy of the tibia was done. Roentgenograms taken on uly 29, 1938, and September 18, 1939, showed persistent tibial and ibular non-union.

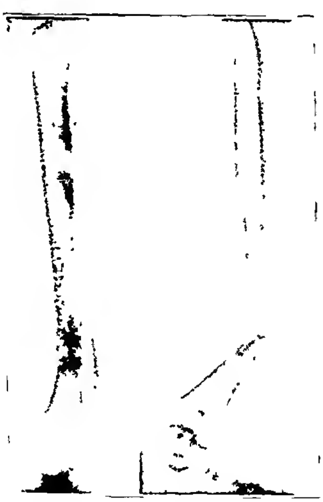

Fig. 2-A

Fig. 2-B

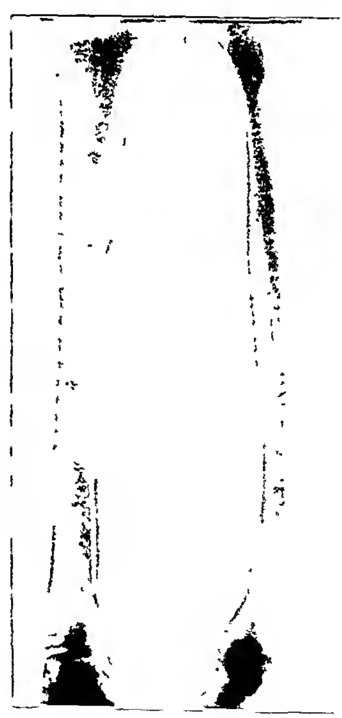

Fig. 2-C

Fig. 2-A: Appearance of the pseudarthrosis before operation.
Fig. 2-B: Appearance of the tibia four months after dual bone-grafting.
Fig. 2-C: Appearance of the tibia seven years and four months after dual bone-grafting.

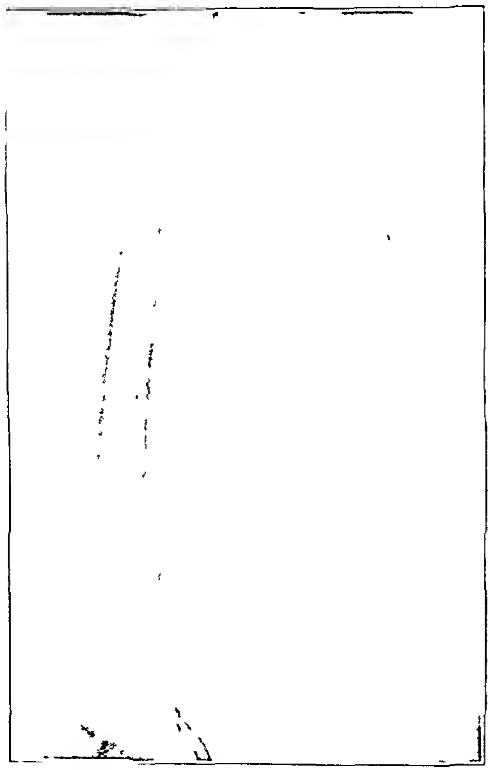

FIG. 3-A

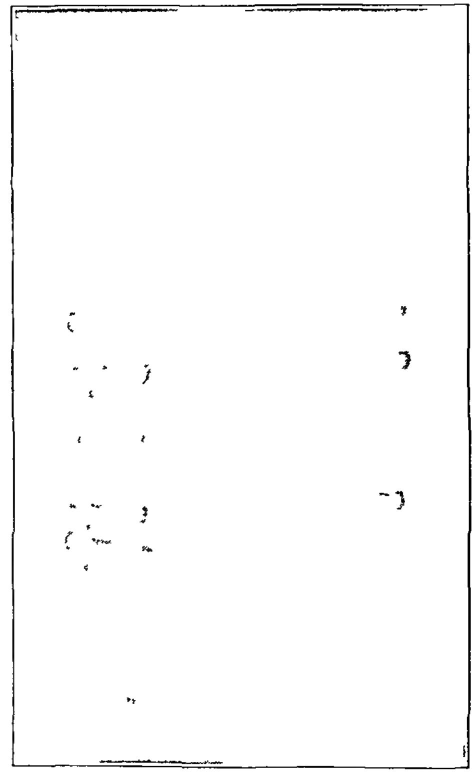

FIG. 3-B

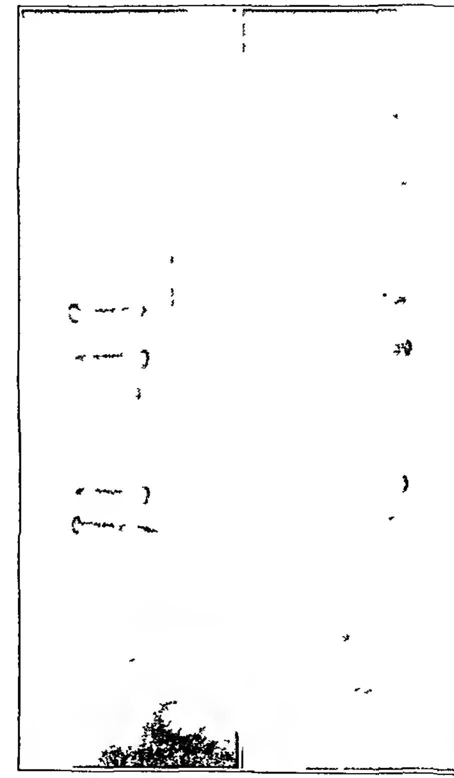

FIG. 3-C

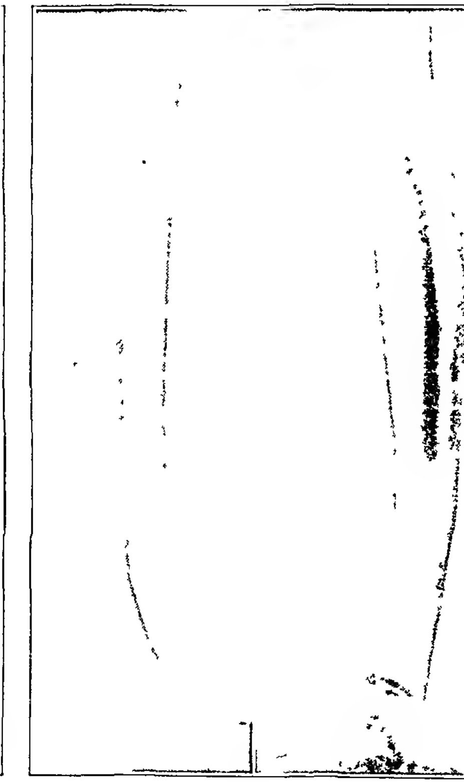

FIG. 3-D

Fig. 3-A: Appearance of the pseudarthrosis before bone-grafting in a boy, aged five.
Fig. 3-B: Appearance of tibia three weeks after application of a dual bone graft. Note proximity of the lower end of grafts to epiphyseal line.
Fig. 3-C: Appearance of tibia nine months after dual bone graft. Note displacement of the lower ends of grafts from the epiphyseal line, due to rapid growth. This was probably in excess of normal, because of stimulation of the epiphyseal line after operation.
Fig. 3-D: Two years and ten months after dual bone graft. There is bony union with re-establishment of medullary canal.

Fig. 3-E: Lateral view of tibia, three years and five months after dual bone graft, shows sclerosis about the fracture site with beginning occlusion of the medullary canal and the beginning of an "insufficiency fracture" in the posterior cortex of the tibia.
Fig. 3-F: Three years and eight months after grafting.
Fig. 3-G: Four years after grafting.
Fig. 3-H: Four years and four months after grafting.

Fig. 3-E

Fig. 3-F

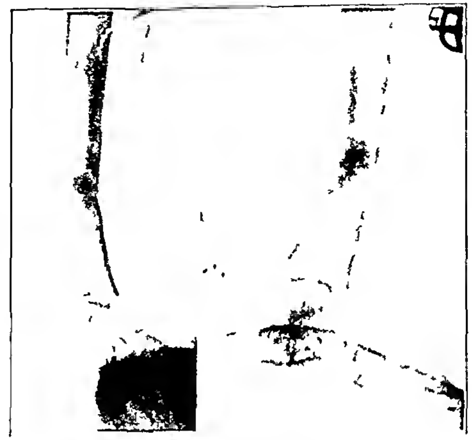

Fig. 3-G

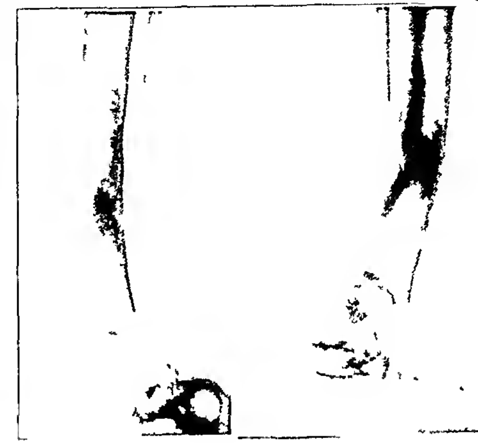

Fig. 3-H

Fig. 3-I

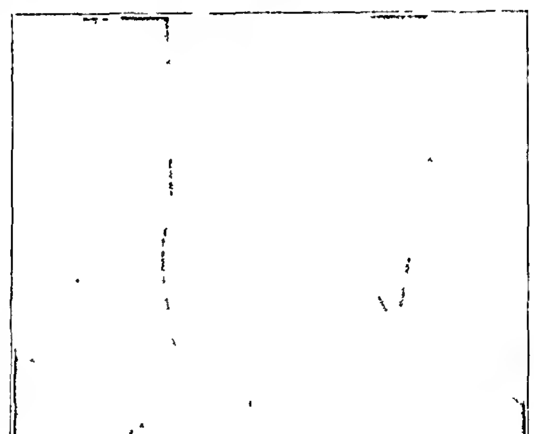

Fig. 3-J

Fig. 3-K

Fig. 3-I: Four years and eight months after operation. Figs. 3-E to 3-H, inclusive, show a gradual advance of the insufficiency fracture, slight increase in angulation at the fracture site and gradual increase in the sclerosis about the fracture site, and obliteration of the medullary canal.

Fig. 3-J. Four years and eleven months after grafting, the insufficiency fracture was completed, as a result of minor trauma.

Fig. 3-K. Roentgenograms of the amputated extremity, nineteen days after completion of the fracture. Note absorption about the fracture site, which occurred despite cast immobilization.

When the boy was four and one-half years of age, an inlay graft was done with the use of bone from the sound tibia. Union did not occur. The leg was supported in a brace until the time of admission to the Clinic. On admission, the pseudarthrosis was evident from clinical and roentgenographic examination. The affected extremity was two and one-half inches shorter than the sound one. Many café-au-lait spots were noted and one tumor (probably a neurofibroma), measuring 1.5 centimeters in diameter, was present on the sole of the left foot.

On March 3, 1943, the day after admission, a dual bone graft was applied; tibial bone from the mother was used. Roentgenograms, taken on April 14, showed the graft in place. Cast immobilization was discontinued on June 4, and a brace was applied. The fracture was clinically solid. On September 11, roentgenograms showed union of the grafts to both tibial fragments. Six days later, on September 17, pain developed in the leg while the boy was walking with a brace. Roentgenograms revealed an incomplete fracture of the tibia, along the course of the proximal screw in the distal fragment. The child was extremely active, but no definite trauma was recalled. By October 13, rapid absorption of the bone ends was evident, even though the leg was immobilized in a cast. Roentgenograms, taken on December 31, showed further increase in the absorption about the fracture site, with narrowing of the bone ends.

With the use of tibial and fibular bone from the father, dual grafting was performed on January 4, 1944; a tibial graft was used posteriorly and a step-cut fibular graft anteriorly, reinforced by two short cortical fibular grafts laterally. Cancellous bone was used to pack around the fracture site. At operation, a fracture occurred through the osteoporotic tibia, just above the ankle at the lower level of the grafts. On October 16, roentgenograms showed union of the grafts to both tibial fragments, with fairly complete obliteration of the fracture line. The supramalleolar fracture had united, with anterior angulation.

The patient has not been seen since October 1944, but, through the courtesy of Dr. Leo Mayer, his brace immobilization has been continued and reports of periodic follow-up roentgenograms have been received. On November 14, 1944, sclerosis at the old fracture site was decreasing. A medullary canal was just beginning to reform. Roentgenograms, taken on October 3, 1945, revealed re-establishment of the medullary canal. The diameter of the tibia was definitely wider at the site of former pseudarthrosis. On December 3, 1946, no definite change in the roentgenograms was noted, except for gradual lessening of the anterior tibial angulation.

Case 7 (Campbell Clinic No. 62253). V. L. S., a white girl, was first seen on February 2, 1944, at the age of eight years. From roentgenograms which were brought in and from her history, the following information was obtained: A deformity of the right leg had been noticed since nine months of age, and had been treated intermittently by casts and braces. Roentgenograms taken on December 22, 1937, showed a double fracture of the tibia and a single fracture of the fibula at the juncture of the middle and lower thirds. Roentgenograms taken on February 1, 1943, showed marked posteromedial angulation of the leg, with narrowing and tapering of the bone ends. On first admission, there was clinical evidence of non-union with a marked valgus deformity of the lower third of the leg. One questionable café-au-lait spot was present on the chest.

A dual bone graft was done on February 8, 1944, paternal fibula being used. Bone chips were packed about the fracture site. Roentgenograms on September 5 showed union of the grafts to the proximal and distal tibial fragments. The fracture line was still present.

In spite of continued cast immobilization, absorption had occurred at the fracture site by November 24, 1945, with recurrence of the deformity. Two days later, on November 26, a second dual bone graft was performed by Dr. R. A. Knight, bone from the opposite tibia being used. The patient was still wearing a cast on June 1, 1946, when she was transferred from our care.

Roentgenograms taken elsewhere on October 19, 1946, showed union, but the medullary canal had not been re-established. On May 16, 1947, roentgenograms showed bony union with amalgamation of the grafts with the tibia. The diameter of the tibia was definitely increased.

DISCUSSION OF UNSUCCESSFUL CASES AFTER THE INITIAL MASSIVE GRAFT

Of the seven cases reported in this paper, four patients required subsequent operative procedures after the initial massive bone graft.

Case 2. Excellent union occurred, but factors predisposing to refracture were an abnormal curve in the tibia, sclerosis about the site of the former pseudarthrosis with narrowing of the medullary canal, and a tibia smaller than normal. This patient, against medical advice, had been carrying out normal activities for a boy of his age for two years, without support. The fracture resulted from definite trauma,- he fell from a merry-go-round. This fracture probably would not have occurred had the extremity been supported adequately. This emphasizes the fact that these patients should wear a brace until puberty, or until the size and texture of the tibia are essentially the same as on the sound side. Satisfactory union was obtained after a second graft was applied.

Case 5. Following the original dual bone graft, bony union occurred and a medullary canal was re-established. Subsequently, an "insufficiency fracture" developed, beginning on the posterior aspect of the tibia at the site of the original non-union. This was converted into a complete fracture by a minor trauma, occurring while the patient was wearing a brace. Following the fracture, the problem was thoroughly discussed with the parents. After taking into consideration the shortening, the calcaneovalgus position of the foot, the possibility of failure or refracture following a second graft. and the function of an artificial limb as compared with that which could be expected from the extremity after a successful second graft, the parents preferred an amputation.

Case 6. In this patient, bony union occurred after the first dual bone graft. A crack developed along the upper screw in the distal fragment. Rapid absorption of the sclerotic bone in this area occurred. This child was obese and the thighs were unusually large in comparison with the legs, making cast immobilization difficult. With these factors in mind and in view of the possibility of failure of a second graft, amputation was suggested to the parents. They, however, preferred a second bone graft; this was done and to date has proved successful.

Case 7. The pseudarthrosis failed to progress to union after the original dual bone graft. In this case, a split fibular graft, taken from the father, was used. This material possibly is inferior for grafting, as compared with tibial grafts. It was taken in the desire to spare the tibia of the donor, as the father was a farmer and needed to return to his plowing at an early date. Union followed the second dual graft, in which autogenous tibial grafts were used.

DISCUSSION OF SUCCESSFUL CASES AFTER THE INITIAL MASSIVE GRAFT

Case 1. This patient has a successful result twenty-two years after a massive onlay graft, performed at the age of twenty-seven months. No shortening has developed in the extremity. This case illustrates the advantage of early grafting.

Case 3. When last heard from, this patient had bony union and a medullary canal had been re-established. The tibia is still small and refracture may easily occur, if adequate bracing is not maintained.

Case 4. This patient obtained solid union after the first dual bone graft, and has not worn a brace for two years. However, he is an exception to the rule, as the fracture occurred through a bone cyst. The ends of the bone were not tapered, and a tibia of approximately normal size developed in a short time.

SUGGESTIONS FOR TREATMENT

The optimal time for bone-grafting has been discussed in the literature. It is the consensus that the older the patient, the greater the probability of union; and that union is obtained with greater ease after puberty. However, the longer the operation is delayed, the more shortening will occur; the leg will be poorly developed; and the deformity, due to anterior bowing of the leg and calcaneovalgus of the foot, will be greater. Case 1 of this series emphasizes the advantage of early successful operations. It is the authors' opinion that the patient should be operated upon as early as practicable, that is, from three to five years of age.

At operation, the surgeon should remember that the bone is small and osteoporotic. The dual graft forms a "bone clamp"; consequently, it is easy to fracture the osteoporotic bone just above the ankle, at the lower end of the graft. This occurred in two of the patients reported in this series; both fractures united promptly. In Case 1, a supramalleolar osteotomy was done on both tibiae to correct the valgus of the ankles; each united in normal time. This emphasizes the opinion that the cause for non-union in congenital pseudarthrosis is a localized factor and does not involve the other bones of the body, nor even the same bone, a few centimeters from the pathological area. The screws should be placed

as far from the area of pseudarthrosis as is practicable, as their presence is apt to predispose to refracture. The technique for the application of a dual bone graft and the advantages of this procedure are outlined in the article published in 1941 by the senior author.

Grafts taken from a bone bank would be ideal for this procedure, as adequate autogenous bone is usually not available for massive bone-grafting in children. The hospitalization of a second member of the family as a bone donor entails additional expense. There is also the hazard of weakening the tibia of the donor, and the possibility of fracture if the tibia is inadequately protected. After sufficient bone has been removed for a dual graft, the donor is required to wear a long leg brace for four to six months.

A long leg cast is applied after the operation and, in small or fat children, a spica may be necessary to ensure adequate immobilization. The immediate postoperative cast is usually changed in approximately ten days, and a snug, well-fitting one is applied. The cast should then be changed often enough to ensure adequate, continuous immobilization until union is apparent in the roentgenograms. This usually requires four to six months. Following cast immobilization, a leather lacer brace is used until a well-developed medullary canal has formed and the tibia is essentially the same size as the normal one. This will usually require the use of a brace until the time of puberty. The type of brace advocated by Kite, in which the leather sleeve laces posteriorly, is superior to one laced down the front of the leg; a solid, well-molded piece of leather on the anterior surface of the leg gives better support to the tibia, which usually has a tendency to become angulated in that direction.

Three types of patients with congenital pseudarthrosis are recognized,—those born with a defect in the tibia; those with fractures developing in a congenital cyst of the tibia; and those born with congenital bowing of the tibia, in whom the bone is small and sclerotic and the medullary canal is diminished in size or absent. In the third type, the tibia usually breaks as the result of minor trauma. Following the fracture, absorption occurs and a typical pseudarthrosis results. In a patient of the third type, osteotomy to correct the bowing of the tibia should not be done, as non-union will develop and, in the minds of the parents, the surgeon will be held responsible for the subsequent train of unfortunate events. This is well illustrated by Case 6 in this series.

The prognosis for fractures developing in congenital cysts is probably more favorable; the bone is better suited mechanically for grafting, because the ends of the bone are not narrowed and pointed, as in the other two types. Also, the medullary canal in both fragments is larger and consequently easier to expose and open, as illustrated in Case 4.

The choice between amputation and bone-grafting may be a difficult one. It is necessary to compare the usefulness of an artificial limb with that of the extremity which can reasonably be expected after a successful bone graft, rather than with a normal leg. An expected shortening in excess of three inches, a considerable residual deformity, such as anterior bowing of the tibia and pes calcaneovalgus, and the constant possibility of refracture of a small, weak tibia may be indications for an amputation. On the other hand, there is no question that some patients are better with a bone graft. The patient presented as Case 1 is now twenty-four years of age, is a registered nurse, married, has a child, and is doing her own housework,—accomplishments difficult to attain with an artificial leg.

CONCLUSIONS

1. In the seven cases reported, ten massive bone grafts have been used. Bony union followed all but one of these operations. This indicates that union can be anticipated in the majority of cases after this procedure. However, in three instances, refracture occurred following union.

2. In one patient, amputation was done after refracture. Bony union has been present following the second bone-graft operation for one and one-half years, two years,

and three and one-half years, respectively. Union has persisted after the first massive graft for two and one-half, seven and one-half, and twenty-two years, respectively.

3. A refracture may be preceded by an increase in sclerosis about the fracture site, narrowing of a previously reformed medullary canal, or an insufficiency fracture. Routine follow-up roentgenograms should be made at six-month intervals to determine if any of these factors are developing, and, if so, surgical intervention may be indicated before a complete refracture occurs.

4. Following refracture, rapid absorption of the bone occurs, and the fracture site soon reverts to a condition simulating that seen in the original congenital pseudarthrosis.

5. It is probably unwise to draw conclusions as to end results in this condition until the patients have become young adults or at least are past puberty. In this series only Case 1 can be considered as having a good end result, according to these criteria.

6. At the termination of cast immobilization, adequate bracing must be maintained until a new medullary canal has developed and the consistency and size of the tibia compare favorably with the normal.

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DISCUSSION

Dr. Halford Hallock, New York, N. Y.: From this and other studies, it is evident that certain factors are present in congenital pseudarthrosis, which prevent the growth of bone or interfere with its integrity after union has been obtained. These are probably circulatory and, in some patients, related to neurofibromatosis. Scarring from previous unsuccessful operations undoubtedly also plays a part. These factors must be considered in any reconstruction procedure, and must constantly be kept in mind during the long period of convalescence that Dr. Boyd has emphasized is necessary for the assurance of a long-term successful result. The combined method of small bone transplants and rigidly fixed dual grafts, which Dr. Boyd employs, physiologically would appear to be the most effective means of dealing with pseudarthrosis. This is borne out by the high degree of early union. Small bone transplants are rehabilitated readily, and the bone grafts with internal fixation provide the immobilization necessary for union. Good bone above and below is necessary for contact with grafts. If this is not possible, or if extensive scarring is present anteriorly, the posterior surface of the tibia can be employed as a site for grafting. Neurofibromatous tissue should be removed, because it may interfere with union or may later be responsible for the recurrence of pseudarthrosis. I agree with Dr. Boyd that if bone sclerosis should increase or an "insufficiency" fracture should develop, after union has been secured, reoperation would be advisable. This should be along the line of reinforcing bone repair and increasing local circulation. Although a refracture spontaneously united in one of our patients at the New York Orthopaedic Hospital, in one it did not. The second patient for several years had showed evidence of an insufficiency fracture at the site of previous pseudarthrosis, and I am sure that reoperation at that time would have prevented non-union. In those patients in whom this operation may fail or in whom conditions are such that a good result cannot be expected, it must not be forgotten that transplantation of the fibula, if feasible, may be of service and may make amputation unnecessary.

Dr. Rex L. Diveley, Kansas City, Missouri: We are indebted to Dr. Boyd for calling to our attention this most difficult condition and for advancing a method which, according to his report, bids fair to being a solution.

When I was asked to discuss this paper, we reviewed our cases, and, of the seven cases followed, we failed to find one with a bony union following operative procedures. Five had had amputations, and the remaining two are considering advised amputations. We have always used the single massive graft or the fibular transplant. After listening to this report, we may feel that the dual graft is the answer.

My personal observations may be summed up as follows: If the pseudarthrosis is complicated by deformity of the foot, ankle, or knee, it would seem advisable to suggest amputation. If the congenital pseudarthrosis is uncomplicated, with not too great a deformity at the point of the arthrosis, the dual bone graft should be tried, according to the technique outlined by Dr. Boyd.

PERITENDINOUS FIBROSIS OF THE DORSUM OF THE HAND

BY MAJOR ROBERT E. VAN DEMARK, LIEUTENANT COLONEL JOHN D. KOUCKY, AND LIEUTENANT COLONEL FREDERICK J. FISCHER

Medical Corps, Army of the United States

In contrast to the usual traumatic tenosynovitis which responds to treatment, a painful, persistent, peculiarly hard swelling, localized over the dorsal metacarpal area and absent in the palm, may follow a blow to the back of the hand. Little attention has been given in the American literature to this condition, the typical etiology and early physical findings of which were originally described by Henri Secrétan in 1901. (It has been called dorsal oedema of Secrétan, and traumatic hard oedema of the dorsum of the hand.) In 1943, Watson-Jones stated that the pathology of this intractable condition was not well understood. Iselin, in his monograph on the hand, has commented on its rarity, stating that he has never seen a case; Cutler and Bunnell in their treatises do not specifically mention the syndrome, apparently because of its infrequency.

An unusual opportunity was afforded to diagnose, observe, and obtain biopsy specimens from two such cases during a recent period of military service. The pathological findings, similar in the two cases and officially confirmed microscopically in the second case at the Army Medical Museum, present certain typical features and establish a fundamental basis for the symptomatology, prognosis, and treatment.

CASE REPORTS

CASE 1. A negro male, aged twenty-eight, was admitted to Bruns General Hospital, Santa Fe, New Mexico, on December 8, 1943, with a transfer diagnosis of synovitis of the extensor tendons of the right forearm and purpura hemorrhagica.

In June 1943, the patient was struck on the dorsum of the right hand by the flat side of a broken rotary-saw blade. Although the skin was not broken, severe pain and swelling occurred immediately. Roentgenographic examination showed no evidence of a fractured metacarpal, which was at first thought to be present. The swelling on the dorsum of the hand extended into the fingers and persisted for three months before subsiding. While in a hospital overseas, the patient had suffered from intermittent bleeding of a variable degree for a five-day period, from the site of an extracted tooth. There was no previous history of unusual or prolonged bleeding.

Physical examination on admission disclosed that the right hand showed a slight thickening of the peritendinous tissue on its dorsum. Due to a painful "checkrein" effect on the extensor tendons of the medial four digits, the patient could not make a tight fist. Motions of the right thumb were free. Routine examination was otherwise not remarkable.

An exhaustive study by the medical staff failed to confirm the diagnosis of purpura hemorrhagica or to disclose any other hemorrhagic disease. While the patient was helping with the routine work about the ward, following admission to Bruns General Hospital, and in the absence of any distinct trauma, severe swelling developed on the dorsum of the right hand. The character of the swelling was firm and non-pitting; peripherally a milder oedema extended into the fingers and borders of the hand, where it gradually faded. Motions of the fingers were painful, and flexion of the fingers was severely limited by pain on the dorsum of the hand.

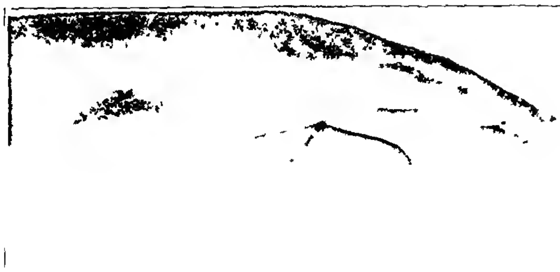

FIG. 1-A

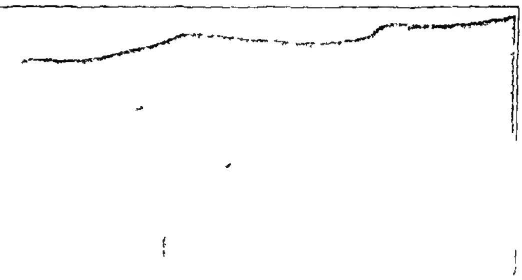

FIG. 1-B

Case 1. Right (Fig. 1-A) and left (Fig. 1-B) hands, showing the marked swelling of the dorsum of the right hand, with milder swelling of the fingers and border of the palm.

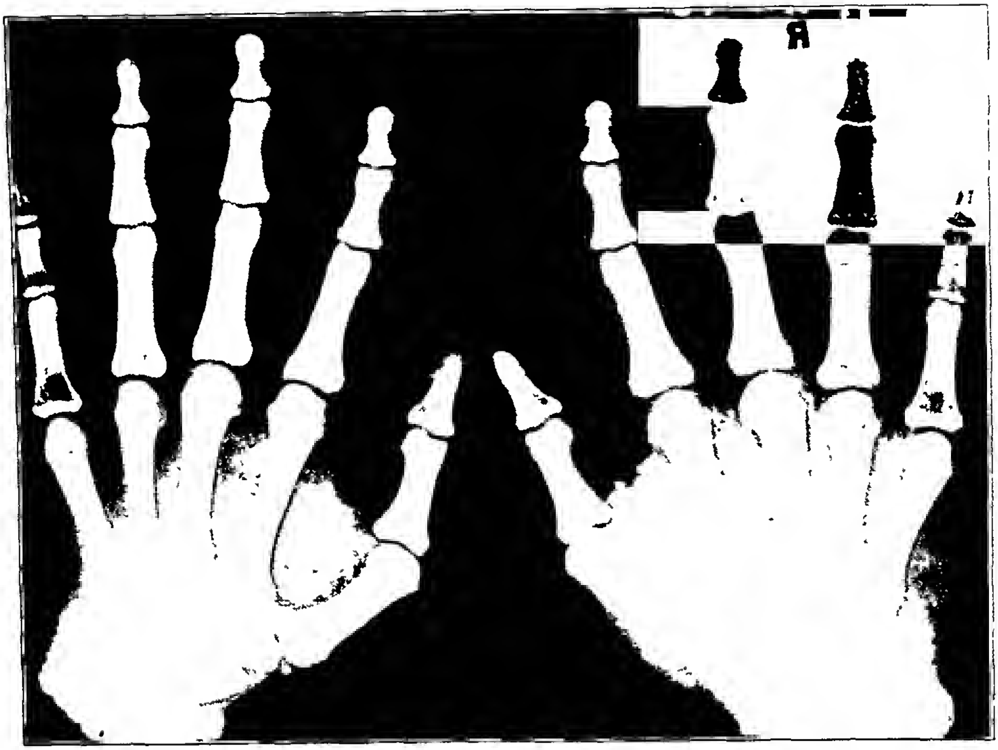

Fig. 1-C

Roentgenograms of the right and left hands, thirteen months after the original injury to the right hand. Note absence of bone atrophy or spotty decalcification.

Fig. 1-D

Right hand at completion of stay in hospital. Compare with Fig. 1-A.

Casts were successively applied to the hand in the position of optimal function; the severe swelling subsided in five months, leaving only a slight thickening. After an additional two months of inactivity, the patient was allowed to use the affected hand. Swelling and pain recurred (Figs. 1-A and 1-B) and exploration was decided upon.

Allergy examination, including skin tests for foods, pollens, and epidermals (fur, feathers, and dander), was negative. A neuropsychiatric examination was negative. Blood-chemistry studies revealed no abnormal values of the icterus index, van den Bergh direct and indirect reactions, non-protein nitrogen, urea nitrogen, uric acid, creatinine, sugar, chlorides, cholesterol, phosphorus, calcium, phosphatase, carbon dioxide combining power, total protein, and albumin-globulin ratio. The phenolsulphonphthalein test, urea clearance, urine concentration, and bromsulphalein tests were within normal ranges. The basal metabolic rate was plus 7. The injection of 0.5 milligram of histamine diphosphate subcutaneously, during the period of quiescence, produced a local swelling which had largely disappeared in four days. The Mantoux skin test was plus 2. Calcium oxalate crystals were present in the urine on several occasions when the patient was placed on a high-oxalate diet. Quantitative urinary-oxalate examination, while not strictly accurate because of technical difficulties, showed a consistently high excretion over a three-month period, as compared with two controls. No exacerbation of symptoms resulted, as far as could be noted, from this diet. No evidence of acid-fast organisms was found in the urinary sediment. Repeated examination of the blood revealed no abnormalities of the blood elements or disturbances in the clotting and bleeding mechanisms. The Kahn test was negative.

As was true in the original case reports of Secrétan, no abnormalities of the bones and joints of the right hand were shown by roentgenographic examination at any time. Thirteen months after the injury (Fig. 1-C) there was no disuse atrophy, although this may appear late in the disease. No abnormalities were found on examination of the lungs.

At operation, a pneumatic tourniquet having been applied, a transverse incision was made on the dorsum

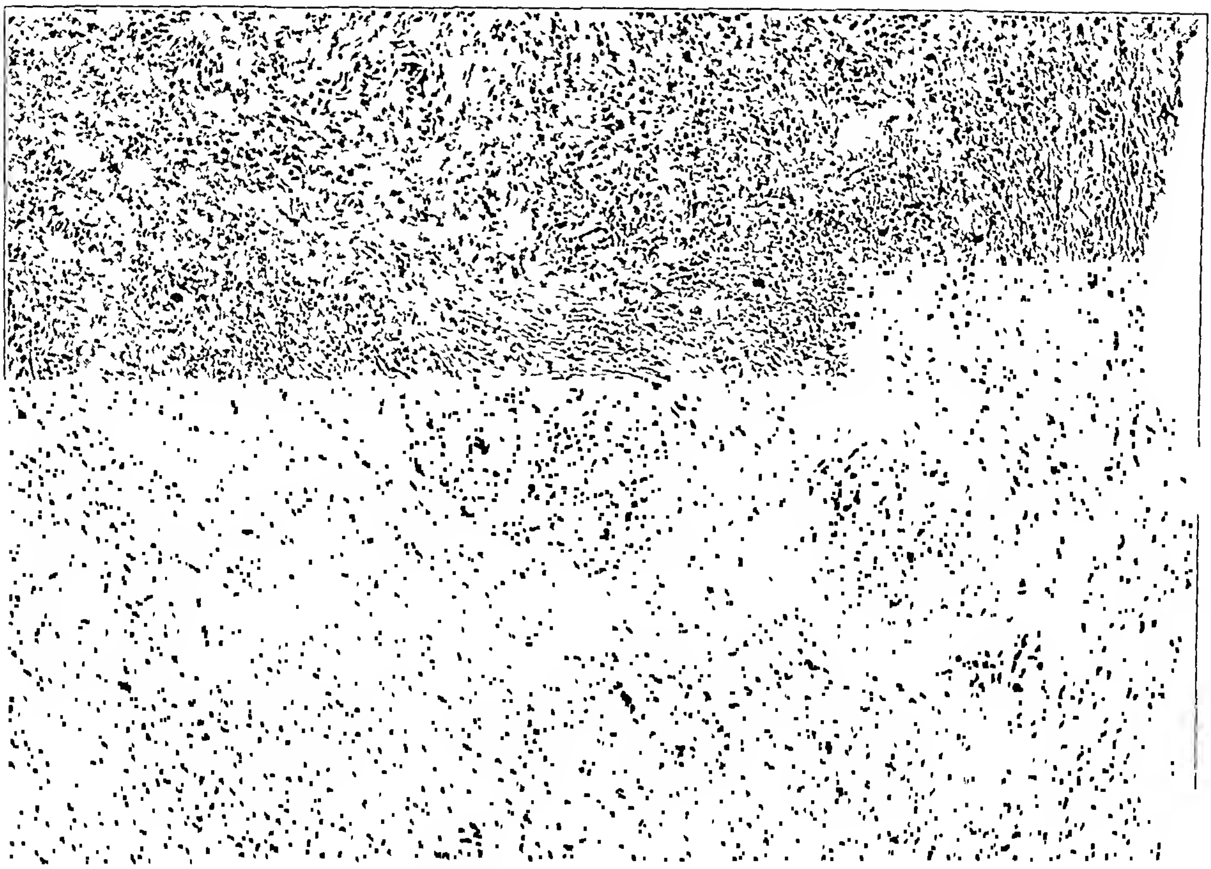

Fig. 1-E

Fibrous peritendinous tissue of collagenous character with numerous small and medium-sized thick-walled vessels; stained with hematoxylin and eosin (×92).

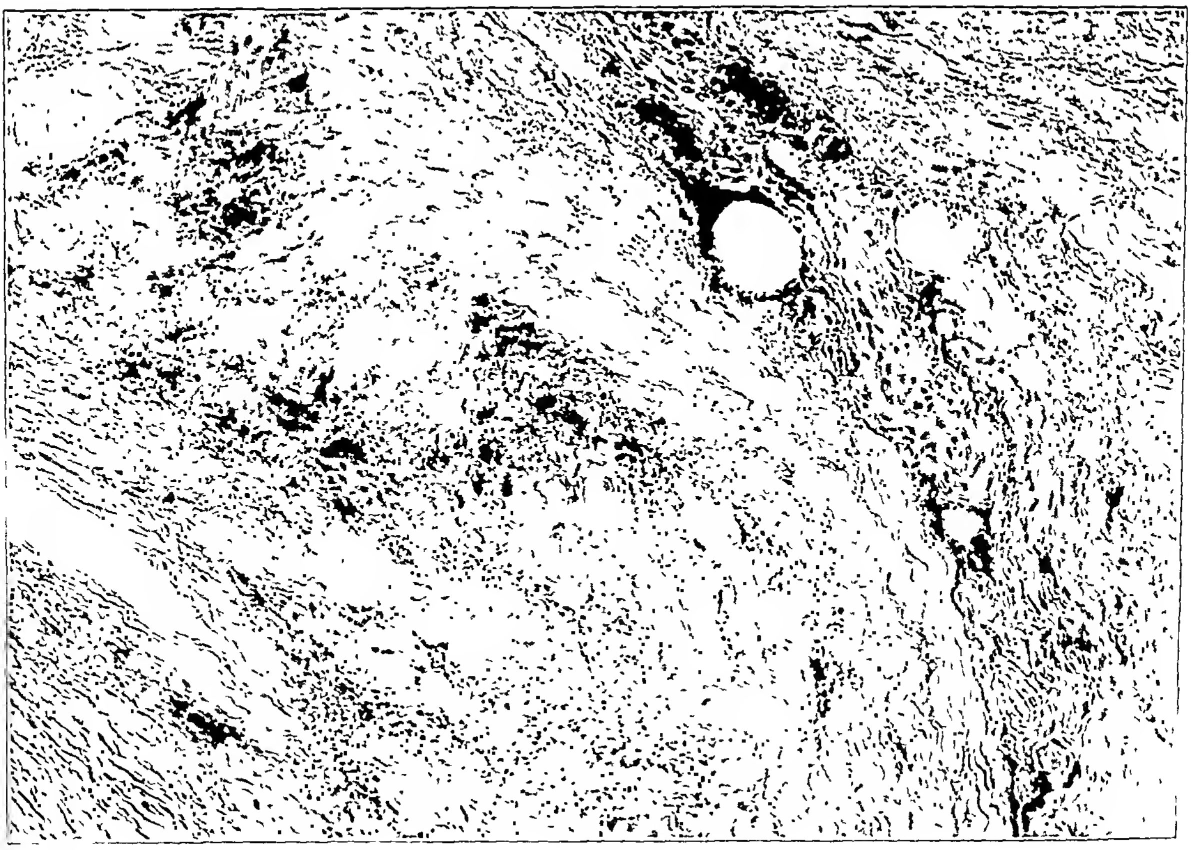

Fig. 1-F

Note the dark-staining intracellular and extracellular iron pigment (Prussian-blue stain) (×184).

of the hand, exposing the subcutaneous tissue; this was grossly fibrotic and entirely covered the extensor tendons of the fingers. The tissue had a light yellow tint, suggestive of previous hemorrhage, and measured approximately 0.5 centimeter in thickness, when incised down to the extensor tendon of the ring finger, which it surrounded. A specimen of the subcutaneous tissue was taken for biopsy. Exploration of the fibrotic mass laterally revealed a hematoma, consisting of clotted blood and serum, deep in the layer of fibrous tissue and superficial to the tendons. The hematoma was evacuated; its volume was approximately six cubic centimeters. The clots were forwarded to the laboratory with the biopsy specimen. A culture of the wound was taken before closure, and a firm pressure dressing was applied.

The wound healed by first intention, despite culture findings of *Staphylococcus albus*, which was probably a contaminant. The swelling entirely disappeared from the fingers and borders of the hand after removal of the pressure dressing, on the fifth postoperative day. At that time the swelling on the dorsum of the hand was diminished approximately 60 per cent. Because of previous reports of delayed wound healing, the sutures in the skin were not removed until the sixteenth postoperative day. Two weeks later the scar broke open at the central portion of the incision, despite adequate care and protection, but promptly healed. The hand was protected in an aluminum splint, and function was gradually resumed. Shortly before discharge of the patient from the Hospital (on November 27, 1944), only a slight thickening was evident on the dorsum of the hand (Fig. 1-D); flexion at the metacarpophalangeal joints was limited almost 50 per cent. In a letter dated March 25, 1945, the patient stated that he was working part time as a laborer and had only slight discomfort in the hand. The authors have since heard indirectly that swelling recurred, but have been unable to get in touch with the patient.

Microscopic Examination of Pathological Specimens: In sections stained with hematoxylin and eosin (Fig. 1-E), the fibrous subcutaneous tissue consisted of dense interlacing bands of collagenous tissue with numerous medium-sized and small thick-walled blood vessels. In the interstices of the collagenous tissue was an intracellular brown pigment, having the characteristic staining reaction for iron (Prussian-blue stain) (Fig. 1-F). Abundant iron pigment was also found lying free between the fiber bundles. Some of the collagenous tissue had undergone hyalinization. The clots from the hematoma were of recent origin.

CASE 2. A white male, aged thirty, was admitted to the Regional Hospital, Camp Joseph T. Robinson, Arkansas, on December 29, 1945, because of a recurrent painful swelling on the dorsum of the left hand. On November 12, 1945, he had slipped on the wet ground, striking the dorsum of his left hand against a tent pole. Localized swelling immediately developed at the site of injury on the dorsum of the hand. After rest the swelling subsided somewhat, only to recur with extreme flexion of the fingers. A roentgenogram had revealed no fracture. The past history was essentially negative.

Physical examination at the time of admission to the Hospital revealed a hard, non-pitting oedema on the dorsum of the left hand, most marked in the region of the distal third of the metacarpal shaft (Figs. 2-A and 2-B). The skin was not discolored and showed no evidence of trauma: no temperature changes were evident. A moderate degree of hypo-aesthesia was present over the dorsal surface of the proximal phalanges of the left fingers. Motion of the thumb was free, but flexion of the fingers was limited because of pain on the dorsum of the affected hand. Roentgenographic examination was entirely negative (Fig. 2-C). Multiple microscopic examinations of the urine revealed oxalate crystals on only one occasion. The basal metabolic rate was plus 13. Blood examinatious, including bleeding time, prothrombin time, clotting time, sedimentation rate, reticulocyte count, hemoglobin, leukocyte count, and differential, were normal. The Kahn test was negative. Blood-chemistry examinations were limited by technical facilities; the blood urea nitrogen, sugar, cholesterol, and icterus index were all found to be within normal limits. A neuropsychiatric examination disclosed symptoms in the left arm, which, to the consultant, were suggestive of hysteria. A consultation revealed no history or evidence of allergy.

On the evening of January 8, 1946, the patient was requested to flex his fingers to the point of pain, in an attempt to increase the swelling; no marked enlargement occurred. On the following morning, January 9, exploration and biopsy of the left hand were performed under general anaesthesia, a pneumatic tourniquet being used on the affected extremity. A small fibrous-tissue plaque, slightly yellow in color, was found over the distal metacarpal area, involving the extensor tendon of the middle finger. The adherent plaque moved with extension and flexion of the finger. On the radial side of the extensor tendon and within the plaque was a small area of granulation tissue, approximately three millimeters in diameter, with evidence of fresh hemorrhage. A small synovial-like sac was found, extending under the plaque and tendon on the ulnar border between the metacarpal bone and the involved tendon. Multiple specimens were taken for biopsy, including the fibrous plaque, the region of the granulation tissue, and a small dorsal peripheral portion of the extensor tendon with its adherent fibrous tissue. The tendon was then freed, and the wound was closed with interrupted sutures.

The wound healed by first intention; the sutures were removed on the fourteenth postoperative day. Three weeks after operation the patient was transferred elsewhere; his subsequent course is unknown.

Microscopic examination of sections of the plaque, stained with hematoxylin and eosin, revealed the presence of collagenous tissue and young fibrous tissue (Fig. 2-D). Prussian-blue stain demonstrated the

presence of iron pigment, both intracellularly and extracellularly (Fig. 2-E). A small area of iron pigment wa noted within the tendon. Free red blood cells were observed in the area of recent hemorrhage. The periphera portion of the tendon was infiltrated with fibroblasts (Fig. 2-F). The diagnosis, as reported by the Patholog Section at this Hospital and officially confirmed at the Army and Navy General Hospital and the Army Medical Museum, was: "Subcutaneous tissue, spontaneous hemorrhage; subcutaneous tissue, fibrosis with collagen infiltration; subcutaneous tissue, hemosiderosis and peritendinous fibroblastic infiltration".

PATHOGENESIS AS SUGGESTED BY PATHOLOGICAL AND ANATOMICAL FINDINGS

The presence of abundant iron pigment in the fibrous tissue, both intracellularly and extracellularly, indicates that the peritendinous fibrosis was a reaction to the absorption of blood. This evidence of hemorrhage has not heretofore been mentioned or demonstrated in the available reported cases or discussions of peritendinous fibrosis of the dorsum of the hand (also known as dorsal oedema of Secrétan and traumatic hard oedema of the dorsum of the hand); neither has the fibroblastic infiltration of the peripheral portion of the tendon been demonstrated microscopically in this condition, as far as we can determine. In the two

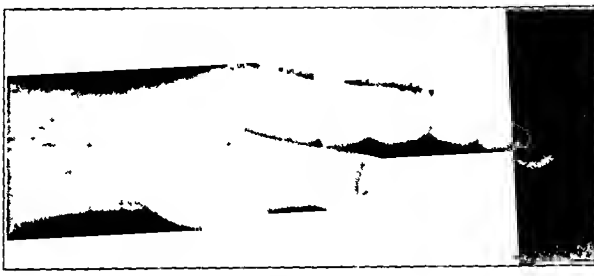

Fig. 2-A

Fig. 2-B

Case 2. Left (Fig. 2-A) and right (Fig. 2-B) hands, showing the moderate swelling of the dorsum of the left hand in the region of the distal portion of the third metacarpal.

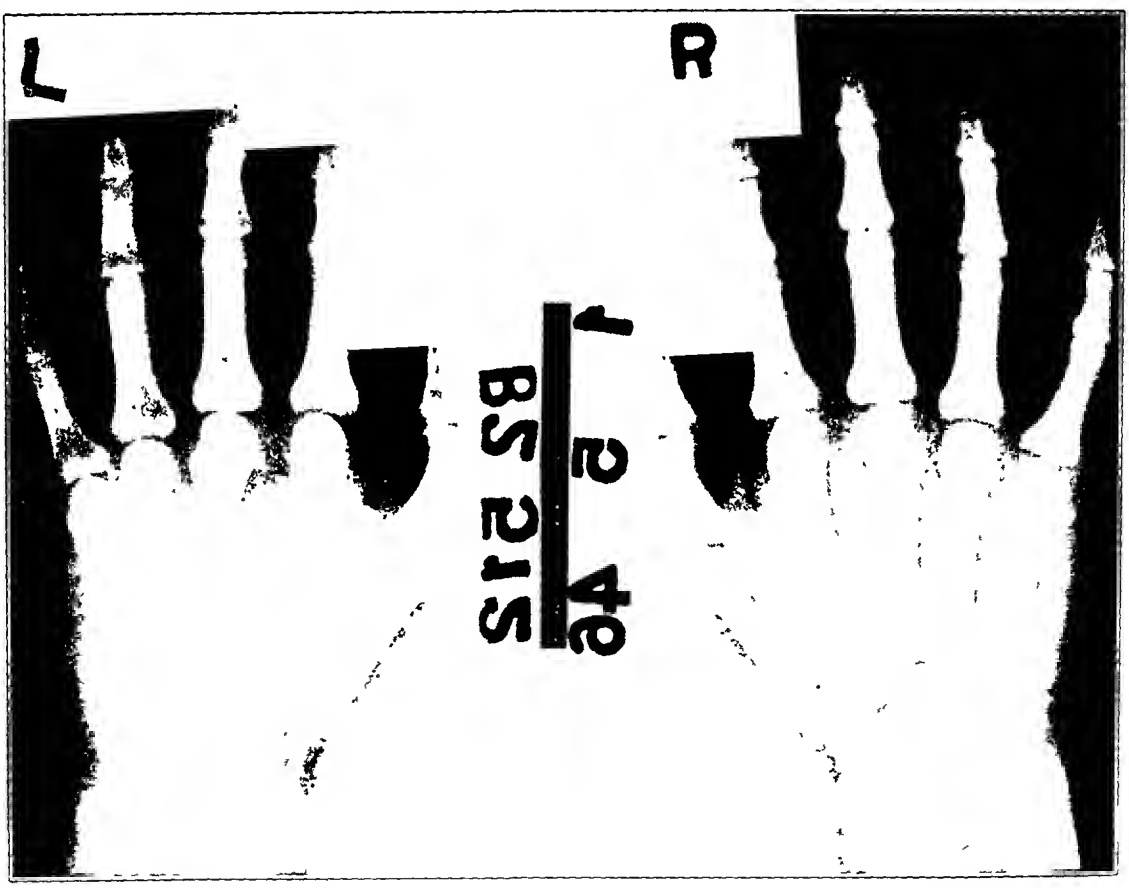

Fig. 2-C

Roentgenograms of the left and right hands, taken slightly less than two months after the original injury to the left hand. Note the absence of bone atrophy or spotty decalcification.

Fig. 2-D

Microscopic section (×92), showing the variation from young fibrous tissue (in the upper left corner) to more mature collagenous tissue (in the lower right corner). Stained with hematoxylin and eosin.

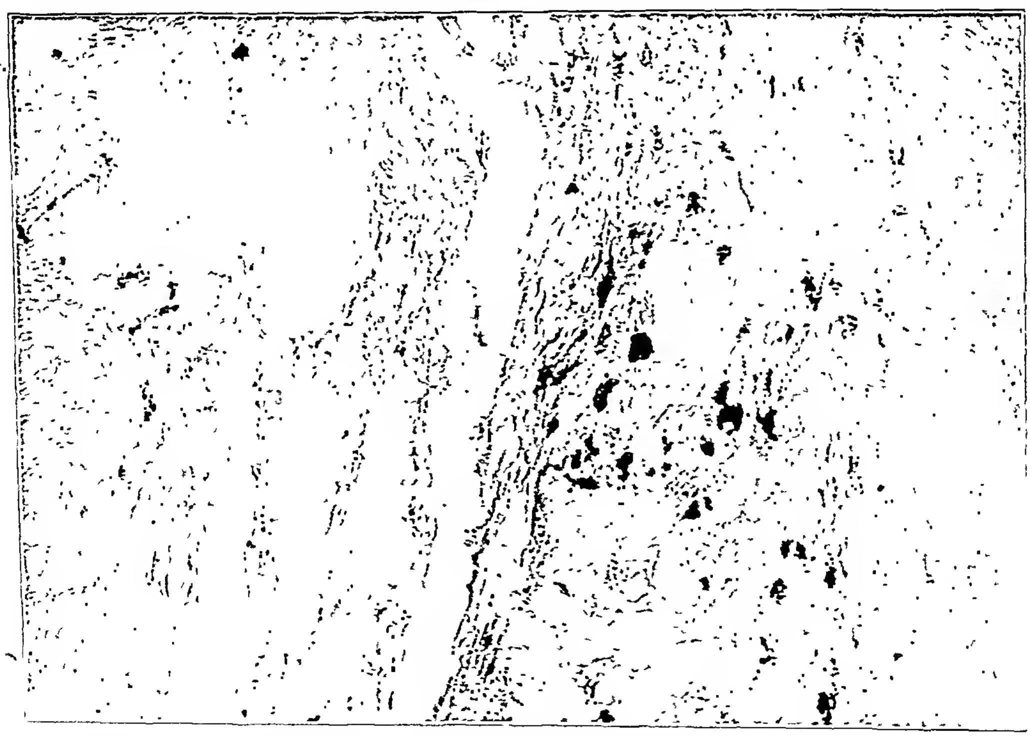

Fig. 2-E

The dark-staining intracellular and extracellular iron pigment is less prominent than in Case 1, because of the shorter duration of the disease. Prussian-blue stain was used (×184).

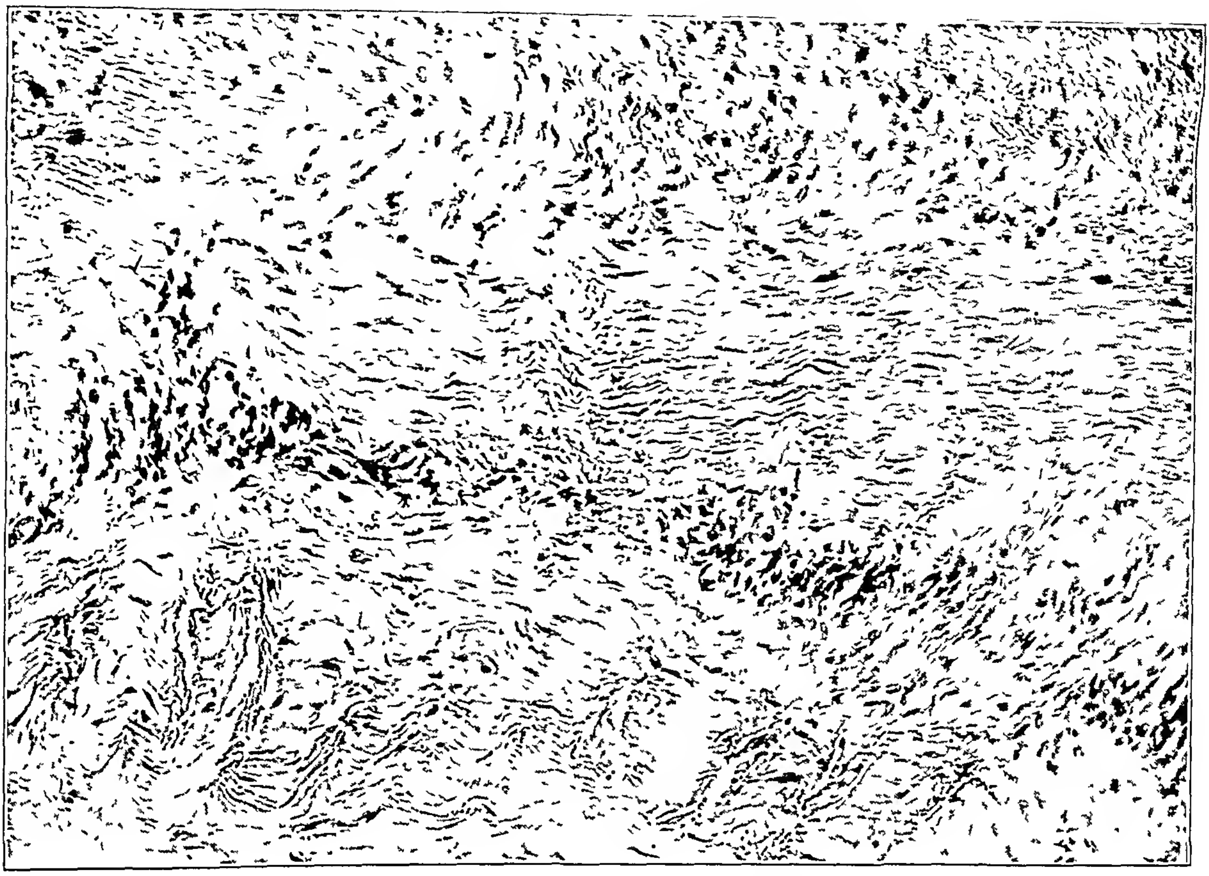

FIG. 2-F

The dorsal peripheral portion of the extensor digitorum communis tendon of the middle finger is seen in the lower left corner; note the infiltration of fibroblasts into and about the peripheral segment of the tendon. Stained with hematoxylin and eosin (×184).

present cases, the initial hemorrhage could reasonably be assumed to be on the basis of severe trauma. As elsewhere, the clotted hematoma (as found in Case 1) is absorbed by the invasion of fibroblasts, which in this condition also infiltrate the adjacent tendon over a considerable length, as shown at operation. (It should be noted that the extensor tendons over the metacarpal area are not protected from an adjacent hematoma by the presence of synovial sheaths, as at the dorsum of the wrist or to a considerable extent on the palmar aspect of the hand and fingers.)

The demonstration of iron pigment within the tendon in Case 2 suggests that a certain fragmentation of the tendon occurs at the time of injury, permitting intratendinous infiltration of blood and possibly predisposing to fibroblastic invasion and fixation of the fragmented tendon. With motion of the tendon, bleeding may easily occur from disruption of the attached young fibrous and granulation tissue, and less easily from tearing of the collagenous tissue, resulting in the recurrence of the hematoma and clinical swelling. Depending upon the degree of absorption of the hematoma, its size can be quite variable; a small hematoma is easily missed in the mass of fibrous tissue. The clotted blood cannot be aspirated and, with the secondary fibrosis, gives rise to a firm, hard swelling, localized to the dorsum of the hand. This latter finding has not been satisfactorily explained heretofore by any neurovascular theory of causation. It should be noted, however, that this focus of hemorrhage, fibrosis, and scarring might well act as a source of an afferent impulse for a reflex arc involving the sympathetic fibers, to produce a secondary oedema on a neurovascular basis. The absence of reported permanent cures following cervical sympathetic procedures in long-established cases is noteworthy; such procedures affect only the secondary phenomena rather than the primary disorder, as demonstrated here.

Anson and his associates have recently completed a detailed study of the several layers of fascia on the dorsum of the hand. It is probable that the absence of superficial

ecchymosis in recurrent peritendinous fibrosis is due to the occurrence of hemorrhage. deep to the superficial layers of fascia; this was true in both of the cases reported. As demonstrated (Fig. 2-F), the area of fibrosis is in the immediate vicinity of the tendons. probably deep to the supratendinous fascia (which Anson has compared to the palmar aponeurosis on the volar aspect of the hand). The superficial lymphatics of the fingers and borders of the palm drain to the dorsum of the hand; their obstruction by pressure of a large hematoma and severe secondary fibrosis, as seen in Case 1, gives rise to the milder oedema of the fingers, as well as that at the border of the palm. Since the osmotic pressure of a relatively large hematoma is unknown, its exact effect on the principal lymphatic channels is a speculative one; a high osmotic pressure would result in an increase in the volume of the hematoma, producing further obstruction of the lymphatics. It is obvious that the pressure of the hematoma and surrounding fibrosis would tend to produce venous stasis by pressure on the dorsal venous arch and its tributaries. In the advanced and more severe case (Case 1) marked wrinkling of the skin, associated with complete disappearance of the finger swelling, followed operative evacuation of the hematoma. The presence of the dorsal fibrosis and hematoma does not obstruct the lymphatic drainage of the central portion of the palm, which drains into the deep lymphatics along the palmar arch; the absence of the palmar swelling is thus readily explained on an anatomical basis.

GENERAL CONSIDERATIONS

Etiology

Males are more frequently affected, particularly laborers, miners, and brewery workers. The incidence of the condition in the United States is probably higher than the paucity of recorded cases would indicate. The possibility of chronic infection has not been generally confirmed by biopsy findings; cases of infectious tenosynovitis constitute a different entity.

Theories like that of Leriche have been advanced to explain the condition on a neurovascular basis [2, 4, 7, 8, 11]; a disturbed sympathetic-nerve control of the lymphatic vessels has been postulated by Schörcher. The skin on the dorsum of the hand is not so firmly fixed by its underlying tissues as that on the palm, which predisposes to subcutaneous swelling; yet it is difficult to understand how a disturbance of the sympathetic nervous system could produce a hard oedema on the back of the hand and fail to affect the bones or soft tissues of the palm. It should be noted that Leriche has produced marked reduction in the size of the swollen hand by a cervical sympathetic procedure. Watson-Jones has suggested that a disturbance in oxalate metabolism may be a factor. In the typical case, the onset of symptoms is precipitated by a blow on the dorsum of the hand, and less commonly by a fracture of a metacarpal bone. As noted by Iselin, an artificial element may be present in certain cases; he points out that self-traumatization of the dorsum of the hand may produce the condition. Coley, in a personal communication, has stated that he is aware of such cases. The predisposing effect of blood dyscrasias or hemorrhagic disease to this affection has apparently received little or no mention in the literature. The relationship of hard post-traumatic swelling to the hand oedema after infections, mentioned by Kanavel, has not been well defined; the deposition of fibrin is apparently less evident in the present cases. The confusion between the two is illustrated by the fact that a case of oedema, following an open suppurating wound with fever and, later, Sudeck's atrophy, has been classified erroneously as traumatic hard oedema [10]. Evidences of psychoneurosis and constitutional inferiority have been reported in certain cases by Bettmann and Leffmann.

Pathological Findings

Microscopic studies have not frequently been made. The pathology has not been clearly understood. On exploration, the peritendinous tissues are found to be hyperaemic and thickened [15]. In one biopsy, described in the early stage of the disease by Schörcher, the tissue was devoid of inflammation. In the later stages of the disease, perivascular in-

flammatory changes are said to occur, and the connective tissue is increased in amount and coarse in character.

Symptomatology

Swelling on the dorsum of the hand occurs shortly after the local injury, and may involve only a portion of the dorsal area. In the severe cases, the skin on the back of the hand has a smooth, stretched appearance. The normal bony prominences become obliterated, and the subcutaneous ridges of the extensor tendons are no longer visible. The hand may feel cool or warm to the touch; no abnormalities of the radial and ulnar pulsations have been reported.

The character of the swelling is firm and hard. In severe cases a milder swelling appears at the borders of the hand and in the fingers, particularly on their proximal dorsal surfaces. The swelling on the dorsum of the hand persists for several weeks or months. With the swelling, an inability to completely flex the fingers occurs; in contrast, motions of the thumb are normal. Later in the course of the disease, finger motion is further inhibited by muscle atrophy and secondary contracture of the joint capsules of the fingers. After the initial injury the pain is most often dull in character, but is increased by extreme flexion of the fingers, as well as by local pressure on the dorsum of the hand. As the swelling subsides, the pain tends to disappear. No sensory or motor changes were reported by Secrétan; the organic basis of diminished sensation, more recently reported by Bettmann, has not been established.

Diagnosis

Usually a fractured metacarpal is suspected when the patient is first seen. The typical history (of acute trauma), the symptomatology, and the roentgenographic findings readily differentiate the condition from the usual traumatic and infectious disabilities of the hand. Sudeck's atrophy and trophic oedema are associated with typical bone changes. Hysterical and functional oedema, due to a prolonged dependent position of the affected limb, is more generalized and is soft in character; personality changes may be readily evident. Less common conditions to be differentiated include causalgia, arthritis, lymphoedema, thrombophlebitis, tuberculosis, and retained foreign bodies.

Prognosis

It has become generally recognized that recurrence of swelling is common, and the number of permanently cured cases is reported by Bettmann as small. Iselin states that the "oedema" persists indefinitely; the incapacity is often 60 to 75 per cent.; and the prognosis is very bad. Watson-Jones has noted a tendency to recurrence even after the swelling has disappeared for a time; he considers the prognosis not good.

Treatment

Numerous methods of treatment have been used. Such therapeutic measures include heat, massage, warm baths and compresses, incision and excision of the involved tissue, cataphoretic histamine and acetylcholine, suggestion, psychotherapy, deep roentgenotherapy, thread drainage, immobilization in plaster-of-Paris casts and splints, compression bandage, low-oxalate diet, various sympathetic blocks, and sympathectomies. A practical form of treatment is suggested by Watson-Jones, who recommends prolonged immobilization in a dorsal plaster splint; this should be continued for several months after the swelling has subsided.

SUMMARY AND CONCLUSIONS

Two cases are presented of soldiers who suffered from recurrent, disabling, hard swelling on the dorsum of the hand, following a severe initial blow. In each case operative

exploration and examination of pathological specimens revealed evidence of old and recent hemorrhage, with fibrous-tissue proliferation and organization in the hemorrhagic area. Infiltration of the extensor tendon by the fibrous tissue gives explanation for the clinical finding of local pain and limitation of movement during flexion of the fingers; also, it is evident that, with extremes of motion of the tendon, disruption of the attached fibrous tissue occurs with further hemorrhage, clotting, fibroblastic organization, and increased fibrosis deep to the superficial fascia. This explains the recurrent, localized, and hard character of the swelling.

In such cases it would appear that the treatment of choice is early operative evacuation of the primary hematoma and ligation of any evident bleeding vessels, followed by a firm compression dressing. Involvement of the extensor tendons during the fibroblastic organization of the adjacent hematoma cannot otherwise be avoided with certainty. In late cases, evacuation of the hematoma should probably be followed by prolonged immobilization, in order to allow maturation of the fibrous tissue and obliteration of the hematoma cavity. The authors are not prepared as yet to state the value in advanced cases of excision of the involved tendons, subcutaneous tissue, and skin, with replacement by a pedicle skin graft and tendon transplants. Such procedures are certainly contra-indicated in cases with a factitial etiology, in old cases with severe joint contracture and marked loss of function, and in those with marked secondary sympathetic-nerve phenomena.

Probably not all cases of peritendinous fibrosis of the dorsum of the hand have a similar basis. In our opinion this present hemorrhagic type constitutes a definite subdivision of a group of ill-defined cases which follow a definite syndrome and are resistant to the usual treatment. The presence or absence of this hemorrhagic type should always be established before other operative procedures, such as various types of cervical sympathectomies, are performed. Permanent good results cannot logically be anticipated with cervical sympathetic procedures in those cases in which fibroblastic infiltration and fixation of the extensor tendons have occurred.

NOTE: Appreciation is expressed for the special examinations, help, and cooperation of all officers concerned with these case studies, particularly Lieutenant Colonel Isadore Pilot, M. C., Captain Robert Hartman, M. C., and Captain David Johnson, Sn. C.

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EXPERIENCES IN THE TREATMENT OF INTRACAPSULAR FRACTURES OF THE NECK OF THE FEMUR*

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From the Instituto Traumatologico, Montevideo

The purpose of this paper is to set forth an analysis of the results obtained in our Clinic over a ten-year period in the treatment of intracapsular fractures of the neck of the femur. For this purpose, we have reviewed 325 cases, with an average follow-up of two years or more; this analysis has led to a series of conclusions, which have pointed the way to our present form of treatment. Similar procedures have been carried out successfully by American orthopaedic surgeons, and our conclusions may be the same as those of our colleagues in the United States.

It is commonly known that the general condition of the patient must be considered before any direct attack can be made upon the fracture of the femoral neck. In many cases, the general condition will contra-indicate any active treatment of the fracture; according to our statistics, 123 cases or 38 per cent. were of this type. Twenty-nine of these patients died between the first and third weeks. Other conditions which precluded fracture treatment were heart failure, cerebral softening, uraemia, senility, et cetera, and there

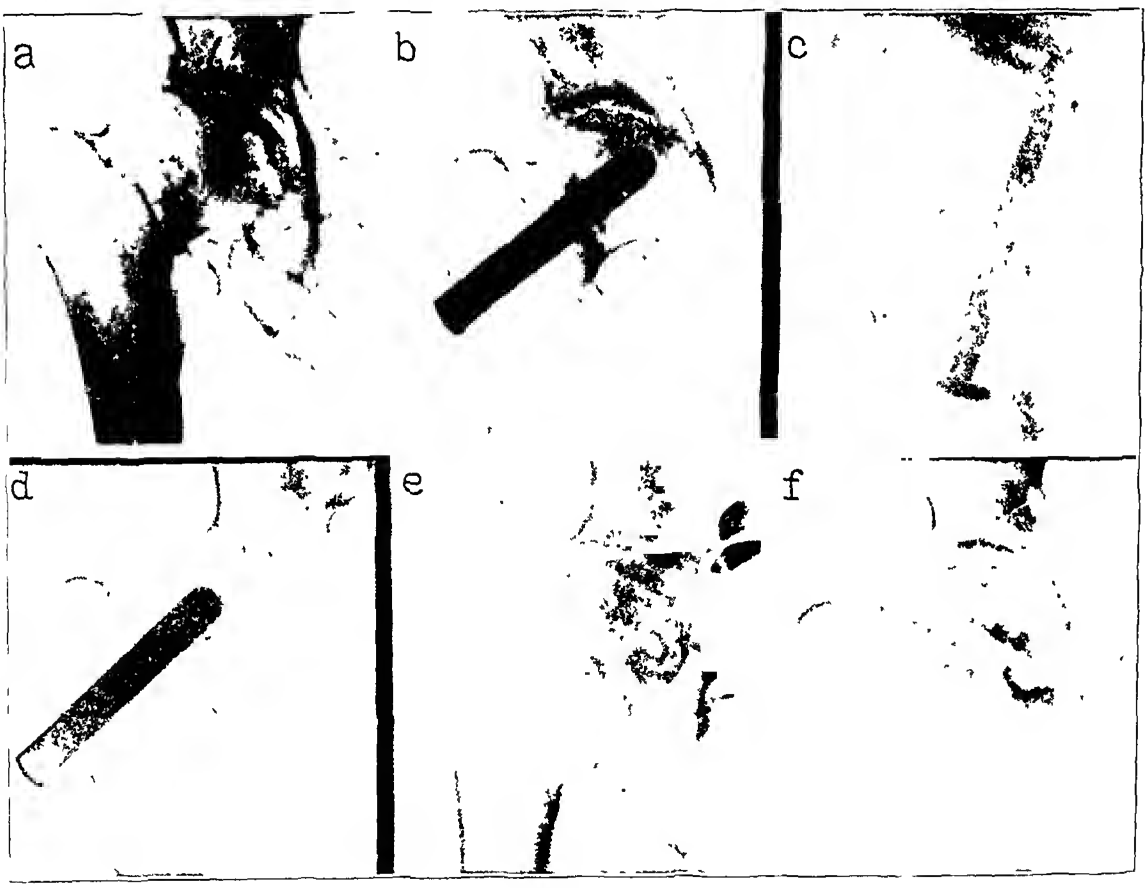

FIG. 1

Case 3321. Modification of Smith-Petersen nail in patient, sixty-eight years old.
a: Preoperative roentgenogram. *b* and *c:* Immediately after operation.
d: Thirteen months after operation, the nail had undergone spontaneous migration and the fracture was reproduced.
e: After removal of the nail. *f:* Five months after osteotomy, the result was very good.

* Read at the Annual Meeting of The American Academy of Orthopaedic Surgeons, Chicago, Illinois January 29, 1947

FIG. 2

Case 1301. Modification of Smith-Petersen nail in a patient, forty-eight years old.
a: Preoperative roentgenogram. *b* and *c*: Immediately after operation.
d: Eight months later, the result is good.

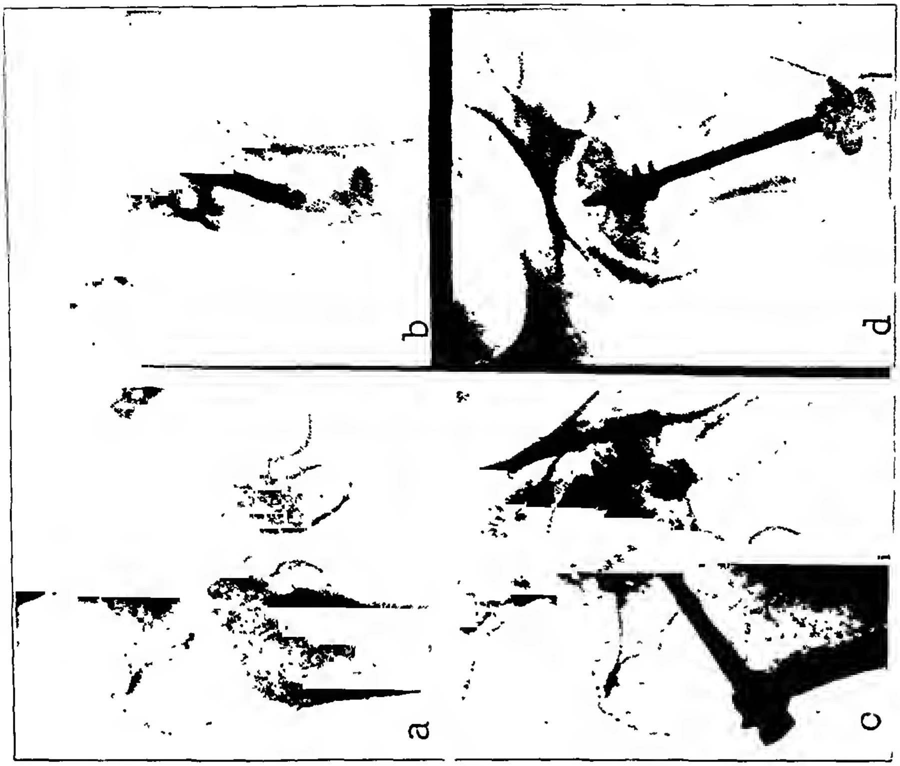

FIG. 3

Case 8215. Godoy-Moreira Vitallium screw was used in patient of sixty-four years.
a and *b*: Immediately after operation.
c and *d*: Three years after operation the result was good.

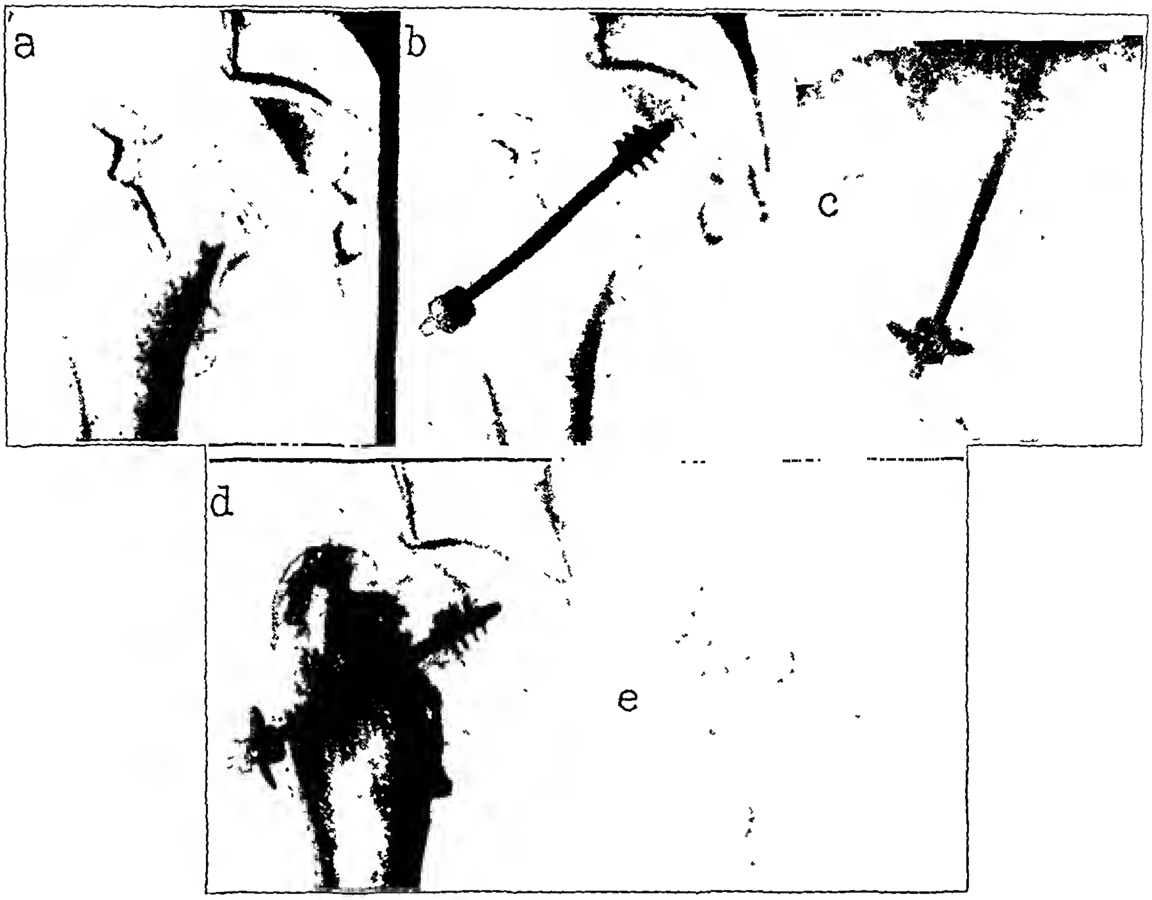

Fig. 4

Case 13876. A Godoy-Moreira screw was used in this patient of seventy years.
a: Before operation. *b* and *c:* Immediately after operation.
d and *e:* Twelve months after operation, callus had not yet formed. The result in this case was bad, with absorption of the neck and external rotation.

were also cases of tabes, syphilitic changes in the hip, tuberculosis, and metastatic disease in the neck of the femur. A rule was finally evolved that no person over fifty years of age with a fracture of the neck of the femur should be operated upon until he had received at least one week of medical observation and treatment. This rule may have helped to attain low mortality rates in our subsequent treatment of the fracture. There were no operative deaths following nailing with the three-flanged nail; of the patients who had had screws applied to the fracture, 2.2 per cent. died as a result of the operation and 7.9 per cent. died as a result of osteotomy.

Of the total of 325 cases reviewed, only 202 actually received treatment of the fracture. In forty of these cases, impaction was present, and the patients were treated in plaster casts with early ambulation. All of this group showed good healing, with excellent function. Four patients were treated with the Whitman plaster, and two of them showed good results. Of the remaining patients, twenty-five were treated by fixation with a three-flanged nail, forty-five had fixation with the Godoy-Moreira screw, seventy-six had primary osteotomy, and twelve had primary bone-grafting.

In the group treated with the three-flanged nail, the ages ranged from twenty-one to eighty-one; 52 per cent. showed bony union roentgenographically, and good function. Complications occurred, however, in this group with good results. One nail was extruded; in one case the head showed aseptic necrosis; in one case there was coxa vara; and in three cases there was absorption about the nail, as well as local tissue reaction to the metal. In 48 per cent. the results were judged as not good: Six patients showed fully developed aseptic necrosis, three had coxa vara, two had non-union, and in one the position was lost after thirteen months. Four of these patients needed subsequent osteotomies.

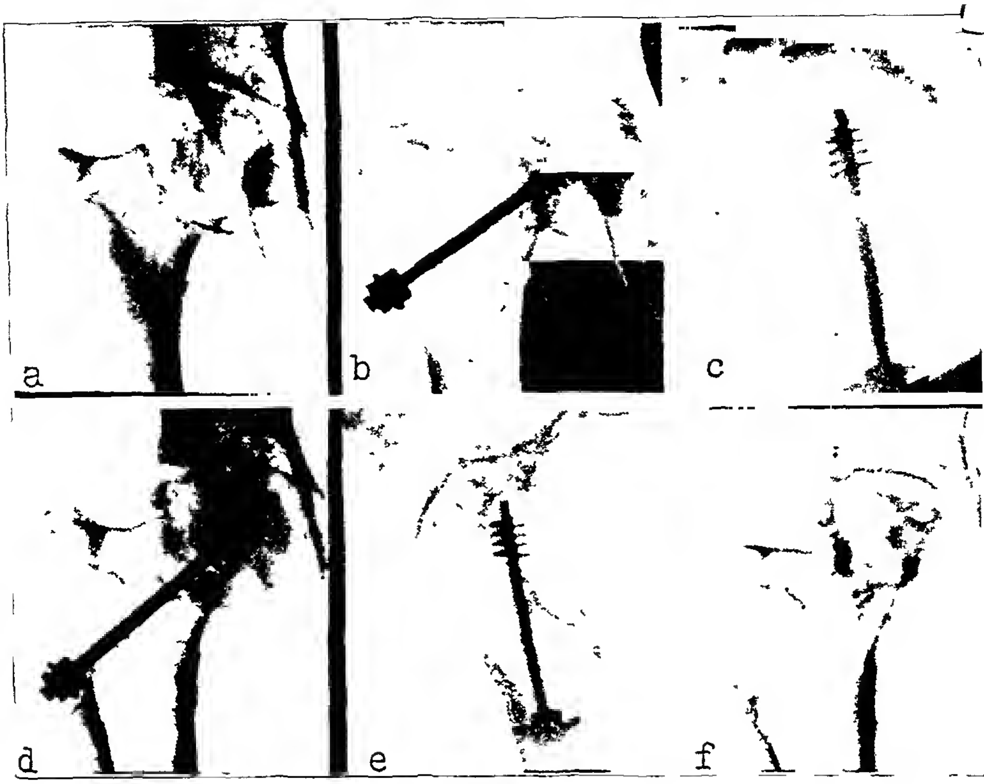

Fig. 5

Case 11338 A Godoy-Moreira screw was used in this patient, aged fifty-seven years.
a: Before operation. *b* and *c:* Immediately after operation.
d and *e:* Twelve months after operation, there was necrosis of the epiphysis
f. Twenty months after operation. The screw has been removed.

In the forty-five cases in which the fracture was fixed with the Godoy-Moreira screw, twenty-four or 53.3 per cent. showed good clinical and roentgenographic results; in 20 or 44.4 per cent. the results were not good; and there was one death or an operative mortality of 2.2. per cent. Here again, aseptic necrosis occurred in ten cases, absorption of the neck

Fig. 6

Case 9571. Thirty months after osteotomy; the results were excellent.

in thirteen cases, and the screws broke in two cases. The screws were removed in ten cases and five patients had subsequent osteotomies.

In seventy-six cases, intertrochanteric osteotomy was the primary treatment. There were six deaths in this group, or an operative mortality of 7.9 per cent.; follow-up in nine of the cases was not possible. Of the remainder, the results in 54 or 88 per cent. of these cases were considered to be very good. The patients were able to walk without support and without pain. However, in no case was flexion possible beyond 90 degrees, and the motions in rotation and abduction were slightly more than a jog. The results were considered unsatisfactory in 7 or 11.7 per cent. of the cases.

Intertrochanteric osteotomy had been our treatment of choice, both as a primary and a secondary operation, in the majority of cases of fracture of the neck of the femur until the past year. This was because the result could be predicted more surely, and also because it was a good procedure when other methods had failed. It was because of the large number

Fig. 7-A

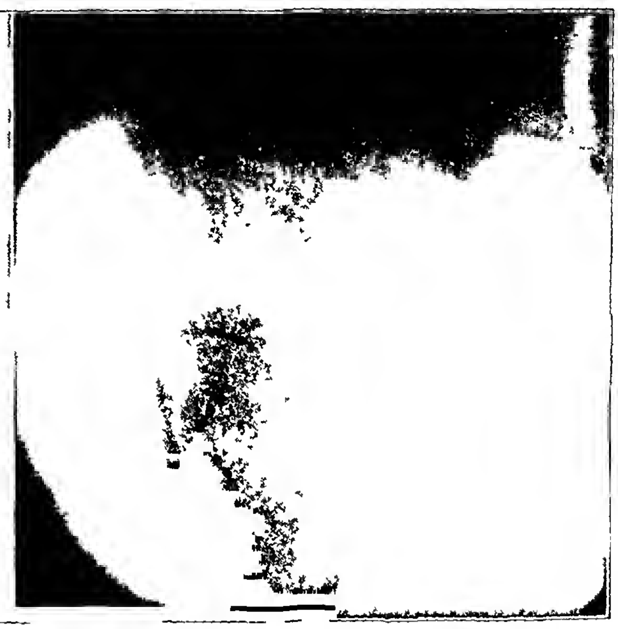

Fig. 7-B

Case 16970 Anteroposterior and lateral roentgenograms of a patient, sixty-four years old

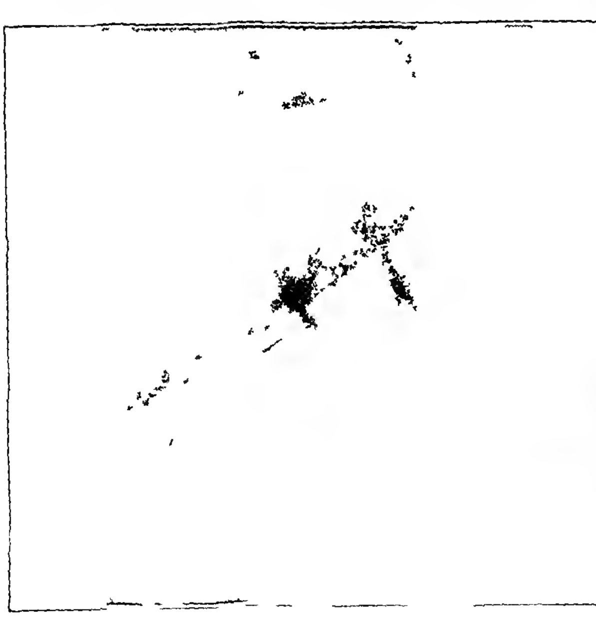

Fig. 7-C

Fig. 7-D

Fig. 7-C: Two weeks after operation.
Fig. 7-D: *Two months after operation. Patient is still in the plaster cast.*

Fig. 7-E

Fig. 7-F

Anteroposterior and lateral roentgenograms three months after operation. The plaster has been removed.

Fig. 7-G

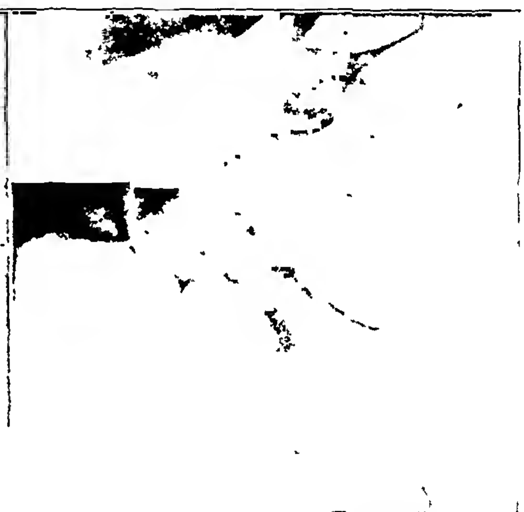

Fig 7-H

Anteroposterior and lateral views, fifteen months after operation.

of failures in cases treated either by the nail or the screw that we began to favor the intertrochanteric osteotomy. Even more important was the fact that no possibility existed of foreseeing or predicting the result with metal fixation, and it made us feel that this form of treatment was uncertain. However, in spite of the fact that results were satisfactory with intertrochanteric osteotomy, we sought a better method in the hope that we could get union and at the same time preserve better function. Since we had previously noted the absence of aseptic necrosis in the cases of slipped epiphyses treated by reduction and bone-grafting, a similar procedure was considered for recent traumatic fractures of the neck of the femur.

To date, twenty-five such cases have had primary bone-grafting after closed reduction. Twelve of these have been analyzed, and all of them show uniformly good results. The point which is most interesting is that, if the roentgenogram shows satisfactory findings in this group at four months, they will be better at six months, and still better in ten months.

Also, there was a notable absence of the surprises which were so usual in the subsequent roentgenograms of cases treated with metal fixation.

TECHNIQUE OF OPERATION

Under spinal anaesthesia, the patient is placed carefully on an orthopaedic operating table, and closed manipulation is carried out as often as is necessary until good reduction has been demonstrated in both anteroposterior and lateral roentgenograms. The operative field is then prepared, and a short incision is made over the upper end and the shaft of the femur. The tubercle of the vastus lateralis is identified, and a wire is started up the neck from a distance two centimeters below this point. The wire is of a known length and, when eight centimeters have gone in, its position is checked by roentgenogram. This is repeated, if necessary, until a favorable position of the wire has been obtained. A perforation along the neck is then made with a hollow drill, which follows the wire as a guide. When this has

Fig. 8-A

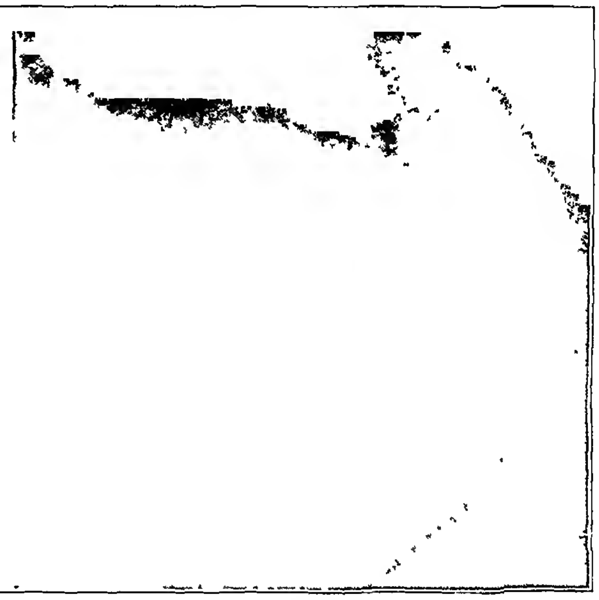

Fig. 8-B

Fig. 8-A: Case 18225. Anteroposterior view, taken before operation, in patient fifty-two years old.
Fig. 8-B: Lateral roentgenogram, taken before operation.

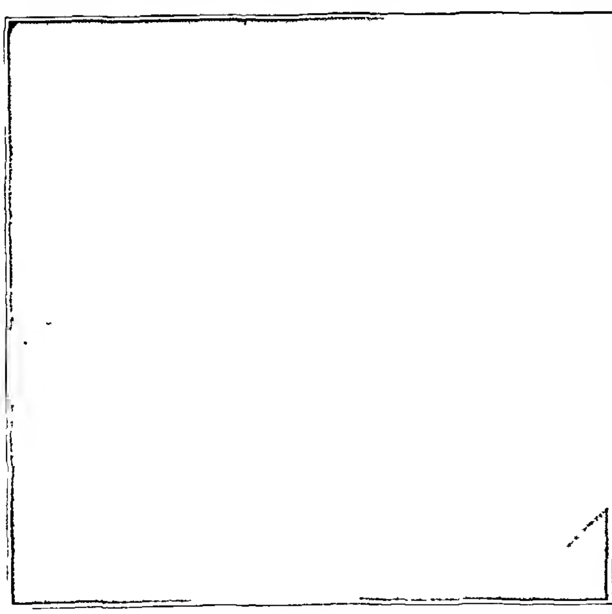

Fig. 8-C

Immediately after bone-grafting operation.

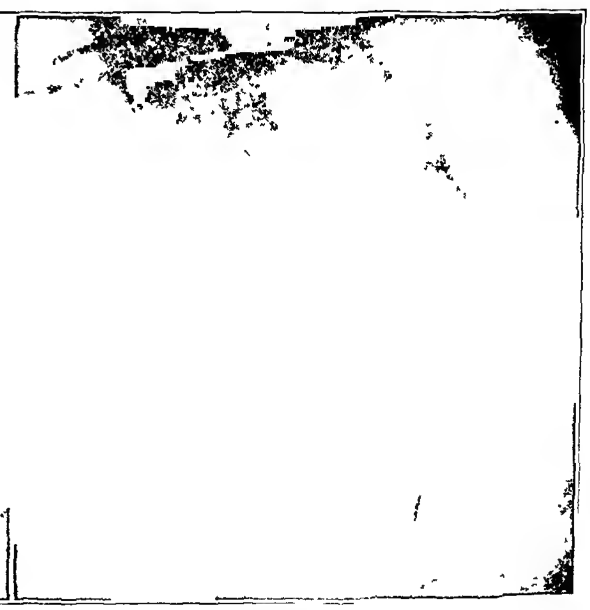

Fig. 8-D

Lateral view.

FIG. 8-E FIG. 8-F

Fig. 8-E: Roentgenogram taken one month after operation, while patient was in a plaster cast.
Fig. 8-F: After removal of the plaster, three months after operation.

FIG. 8-G FIG. 8-H

Fig. 8-G: Lateral view, eight months after operation.
Fig. 8-H: Hip mobility is normal, eight months after operation.

gone in the appropriate distance, it is removed and a drill of larger size is introduced. In order to hold the position of reduction, we have frequently fixed the head to the neck by two wires, one at the superior portion and one at the inferior portion of the head. In using reamers or progressively larger drills, care must be taken to avoid making a false path, and this is accomplished mostly by the "feel" of the instrument.

A bone graft, triangular in shape and including the tibial crest, is taken from the tibia. The desired length and width of this graft should be determined by the channel made in the neck of the femur. The graft is then driven carefully into the created tunnel, care being exercised that it is the proper size and that it goes in the proper direction. Roentgenograms are again taken to be certain of the correct position of the graft, and the films must be interpreted very carefully. Usually at least eight roentgenograms are necessary, and often more. The wound is then closed and the patient is placed in a single hip spica for three months.

CONCLUSIONS

1. A relatively large number of fractures of the neck of the femur occur in which no active attention can be given to the fracture, because of the general condition of the patient. About 65 to 70 per cent. of the cases receive active treatment for the fracture.

2. Various methods of treatment with metallic fixation leave a great deal to be desired as to the outcome.

3. Osteotomy as a primary therapeutic procedure allows more certainty in the prediction of results, but demands the sacrifice of part of the function of the hip.

4. Primary bone-grafting after closed reduction eliminates the disadvantages of the methods described here; that is to say, it will more surely prevent aseptic necrosis and neck resorption, and at the same time it will maintain better hip function. At the present time, we prefer this method of treatment to all others, because the results have been better.

PSEUDARTHROSIS IN THE LUMBOSACRAL SPINE *

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Some in this audience will remember the furor with which surgical fusion of the spine was greeted when it was first proposed. Despite the fact that various complications soon became apparent, this procedure, at first proposed for tuberculosis of the spine, was gradually extended to include the treatment of many conditions. Among these were numerous disabling lesions involving the lumbosacral area. The obvious dangers of mortality and complications after such operations have been fairly well established, and accounts of pseudarthroses or failures of continuity in desired fusion areas have been recounted in a few series. Comparative statistics or percentages of pseudarthroses developing as a result of operative procedures employing varying techniques, carried out by the same limited personnel, are, to our knowledge, not available. While the operations reported here were all performed by three surgeons, they were carried out at six different institutions. This would indicate that the results were not due to unusual hospital advantages, but were the result of uniform surgical technique and ability. The mortality and complications have proved to be of minor importance. Failure of accomplishment of the desired end—namely, successful arthrodesis of a selected series of vertebrae in the lumbosacral region—has proved to be of major importance. We shall herewith review and report failures of fusion occurring in a consecutive series of patients in whom arthrodeses were attempted across the lumbosacral joint. The paper will be divided into two main parts: first, the incidence of pseudarthrosis in fusion of the lumbosacral spine; and, second, statistics regarding the repair of pseudarthroses.

* Read at the Annual Meeting of The American Orthopaedic Association, Hot Springs, Virginia, June 27, 1947.

TABLE I

RELATION OF PSEUDARTHROSIS TO EXTENT OF FUSION AND NUMBER OF PATIENTS WITH SOLID FUSION NOT RELIEVED OF PAIN

Fusion Intervals	No. of Operations	Pseudarthroses		Pseudarthroses		Solid Fusion without Relief of Pain	
		No.	Per cent.	With Pain	Without Pain	No.	Per cent.
Fifth lumbar to first sacral	145	5	3.4	3	2	17	11.7
Fourth lumbar to first sacral	357	62	17.4	36	26	15	4.2
Third lumbar to first sacral	78	26	33.3	15	11	1	1.3
Second lumbar to first sacral	18	6	33.3	4	2	0	0

INCIDENCE OF PSEUDARTHROSIS IN FUSIONS OF THE LUMBOSACRAL SPINE

Pseudarthroses in the Total Series

Clinical Incidence: In this series of cases, 647 operative procedures were carried out on 594 patients. The average postoperative follow-up period has been thirty-four months. No result has been accepted as regards solidity of fusion with less than one year of follow-up, unless controlled by both lateral roentgenograms in flexion and extension and by anteroposterior roentgenograms in right and left bends. Among the 594 patients upon whom spine fusion was performed, pseudarthroses developed in 119 instances or 20 per cent. This represents a percentage of basic failure which requires improvement.

True Incidence: Scientifically and factually, it has seemed important to determine the development of pseudarthroses according to the number of intervertebral spaces involved. Among the 594 patients, 1,329 spinal intervals were bridged. Pseudarthrosis occurred at 161 intervals among these patients, or 12.1 per cent. This represents the relative inefficiency of this type of surgery.

Incidence of Pseudarthrosis as Related to Extent of Fusion: We had expected that the percentage of pseudarthrosis would rise rapidly as the number of spinal intervals which were crossed increased. This was found to be true. When the fifth lumbar interval alone was bridged, pseudarthrosis developed in only 3.4 per cent.; when fusion of the fourth and fifth lumbar intervals was attempted, pseudarthrosis developed in 17.4 per cent.; as another interval was added, covering the third, fourth, and fifth lumbar intervals, the proportion rose rapidly to 33.3 per cent., and remained relatively the same as other intervals were added (Table I). A patient was often relieved of preoperative symptoms, in spite of the development of pseudarthrosis. Of all patients in whom pseudarthroses developed, 41.4 per cent. were relieved of the pain and disability which had been present before operation.

This analysis showed that a certain number of patients were unrelieved, even though solid fusion developed. This percentage rapidly decreased from 11.7 to 0 as the number of intervals successfully crossed was increased from one to four. To secure relief of symptoms for the greatest percentage of patients requires, therefore, a delicate balance. As the area of fusion is lengthened, there is an increase in the incidence of pseudarthrosis, but a marked decrease in the number of patients with solid fusion who are unrelieved of their symptoms.

Influence of Bending Roentgenograms on Results: Failure of fusion was demonstrated much more frequently when roentgenograms of front and side bending (biplane) were

superimposed (Fig. 1) than by the use of flat roentgenograms and clinical observation. In these biplane roentgenograms, the lateral flexion and extension plates should show the fused elements completely superimposed. In the superimposed anteroposterior lateral-bending roentgenograms, the fused elements appear as if stereoscoped, but the borders of the bodies of the spinous and transverse processes are parallel[1]. As early as 1933, lateral flexion and extension roentgenograms were occasionally used (Fig. 2). For more accurate determination, we frequently connect comparable points on the vertebrae with lines and superimpose these. Since 1940, roentgenograms with motion in two planes have been superimposed in order to denote solid arthrodesis. The use of such superimposed roentgenograms has increased the *known* percentage of pseudarthrosis, when tabulated both as to clinical incidence and true incidence.

In a review of this series of cases, only 11.8 per cent. were diagnosed as having failure of fusion by clinical judgment and flat roentgenograms. In 21 per cent. of the patients, pseudarthrosis was shown by biplane bending roentgenograms. The authors believe that the increased percentage shown to have pseudarthroses by the bending roentgenograms indicates accurately that clinical judgment, aided by flat roentgenographic plates, does not truly establish the number of pseudarthroses present in any series.

Relation of Pseudarthrosis to Primary Lesion for which Arthrodesis Was Performed

Posterior Herniation of the Intervertebral Disc: Here are grouped only those cases which had frank herniations of the disc with unequivocal extrusion of material. All cases with bulging of the disc, et cetera, are excluded and placed under the heading of lumbosacral strain. Of the typical posterior herniations of the intervertebral disc, pseudarthroses de-

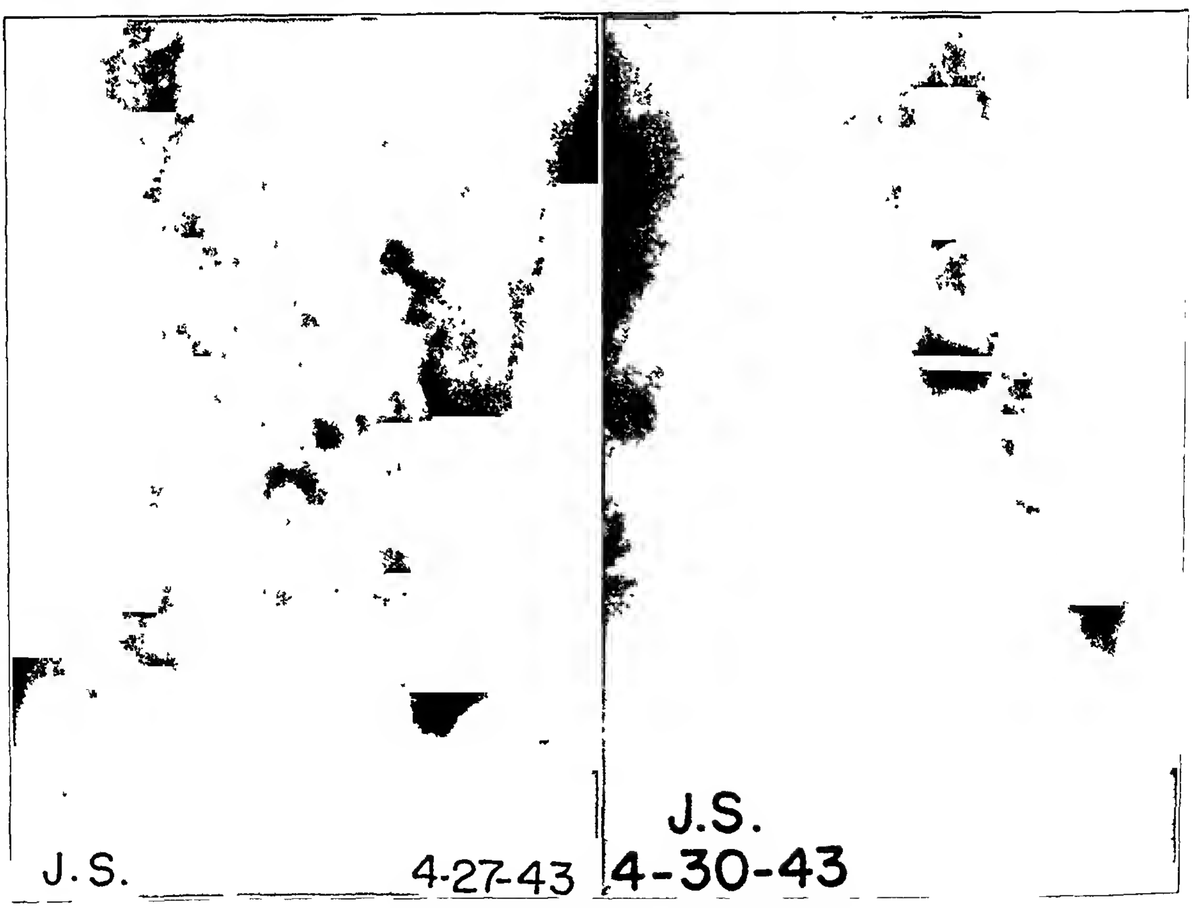

Fig. 1

Biplane bending roentgenograms, superimposed, are essential for determination of the presence of pseudarthrosis. In the lateral view, such roentgenograms should be accurately superimposed in the arthrodesed area. In the anteroposterior view, the elements will appear as if stereoscoped; but the borders of the vertebral bodies, et cetera, will be parallel if fusion is solid.

TABLE II

RELATION OF PSEUDARTHROSIS TO PRIMARY LESION FOR WHICH FUSION WAS PERFORMED

Diagnosis	No of Operations	Pseudarthroses	
		No.	Per cent.
Posterior herniation of intervertebral disc	158	18	11 4
Lumbosacral strain	289	65	22 5
Tuberculosis	31	5	16 1
Spondylolisthesis	69	16	23 2
Arthritis	37	11	29 7
All others	16	4	25 0

veloped in 11.4 per cent. (Table II). This low percentage is believed to be due to the universal use of the clothespin graft, plus quantities of additional bone.

Lumbosacral Strain: In this group were placed all patients with chronic lumbosacral backache, non-specific sciatic symptoms, and lesions, the basic pathology of which was not clearly disclosed before or after operation. Failure of fusion developed in 22.5 per cent. Before 1940, when biplane bending roentgenograms were not required, there was an incidence of pseudarthrosis of only 15 per cent. Following 1940, with all cases controlled by such roentgenograms, the percentage of pseudarthroses rose to 21.3. Here, again, is clear indication that pseudarthroses are missed with flat roentgenograms and clinical examination alone.

Tuberculosis: Under this heading were included only known tuberculous lesions of the spine. Any questionable lesions of this nature were placed under the heading of arthritis. Pseudarthroses developed in 16.1 per cent. of cases.

Spondylolisthesis: Spine fusion was carried out on sixty-nine occasions, with development of pseudarthrosis in 23.2 per cent. Before 1940, the incidence of pseudarthrosis was

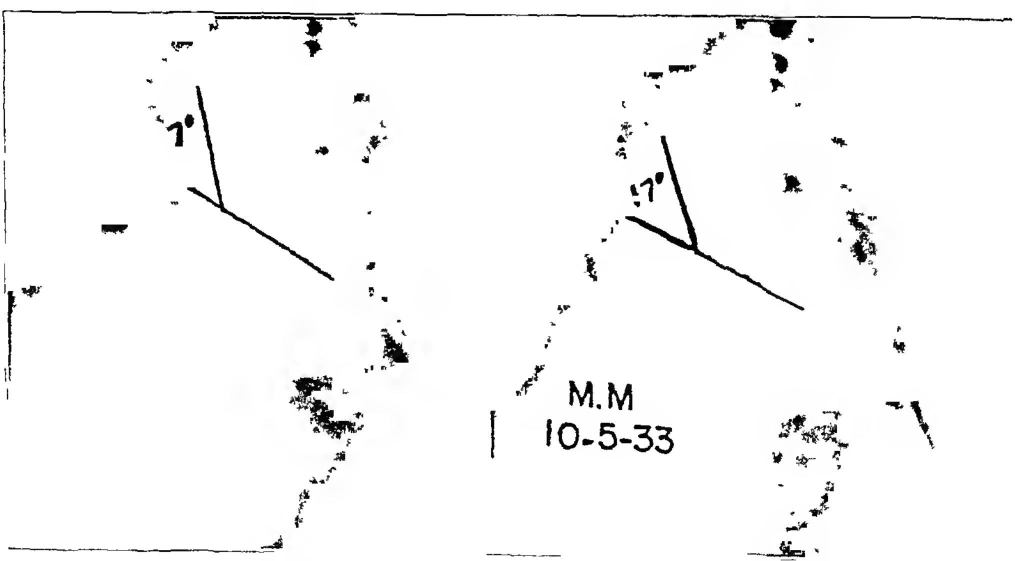

FIG. 2

Lateral views of flexion and extension roentgenograms alone are not sufficient. These were used as early as 1933, but pseudarthroses have been shown to exist by the anteroposterior lateral-bending views, when the lateral views in flexion and extension superimpose with complete accuracy.

TABLE III

DEVELOPMENT OF PSEUDARTHROSIS AFTER VARIOUS TYPES OF OPERATIVE PROCEDURE

Technique	No. of Operations	Pseudarthroses	
		No.	Per cent.
Trisacral fusion	85	9	10.6
Double clothespin graft	356	68	19.1
Iliac strips	74	16	21.6
Local bone	40	12	30.0
Hemifusion	45	14	31.1

TABLE IV

REPAIR OF PSEUDARTHROSIS

Number of pseudarthrosis repairs		43
Repaired once	29	
Repaired twice	4	
Repaired three times	2	
Total number of patients	35	

35 per cent. After 1940, when double clothespin grafts of iliac bone supplemented by iliac strips were first used, the incidence of pseudarthrosis dropped to 16.3 per cent.

Arthritis: Of thirty-seven patients treated by fusion operation, pseudarthrosis developed in 29.7 per cent.

All Others: There were sixteen cases with such diagnoses as foreign body, fracture of the lamina, hemivertebra, or scoliosis. Pseudarthroses were found in 25 per cent.

Pseudarthroses Developing from Various Types of Operative Procedure

Trisacral Fusion: The lumbosacral joints were crossed in this operative procedure in eighty-five instances, with the development of pseudarthrosis in 10.6 per cent. (Table III). In the majority of cases this operative procedure was performed where the fifth lumbar vertebra alone was added to the sacrum, covering only one interval. For this reason a high percentage of successful arthrodeses resulted. Further analysis of the series shows that most of the pseudarthroses occurred where both the fourth and fifth lumbar interspaces were crossed. Where the fifth lumbar vertebra alone was arthrodesed to the sacrum, only 3.3 per cent. of pseudarthroses occurred. When both the fourth and fifth lumbar vertebrae were fused to the sacrum, 29.2 per cent. of pseudarthroses appeared, almost ten times as many as when a single interval was crossed.

Double Clothespin Graft: The double clothespin graft was used in 356 operations; 19.1 per cent. of pseudarthroses resulted. Analysis again shows that the number of intervals crossed determines the percentage of pseudarthrosis encountered. In operations in which the fifth lumbar vertebra was fused to the sacrum, one case of pseudarthrosis was found or 2.1 per cent. When two spinal intervals were crossed, 16.2 per cent. of pseudarthrosis occurred. When three intervals were crossed, the pseudarthrosis rate rose to 39.2 per cent.

Iliac Strips: In seventy-four operations, strips of iliac bone were used without other support; pseudarthroses developed in 21.6 per cent. This is nearly as good a record as with the double clothespin graft. Immediate stability following operation, however, is lacking.

Local Bone: When bone from the posterior elements of the vertebrae themselves was used, without reinforcement of osseous material from adjacent structures, the percentage of pseudarthrosis rose to 30.

TABLE V

LOCATION OF PSEUDARTHROSIS AND INTERVALS INVOLVED

Multiple Locations		Intervals Involved	
No. of Interspaces	No. of Cases	Location	No. of Times
1	19	Second lumbar	3
2	12	Third lumbar	6
3	4	Fourth lumbar	31
4	2	Fifth lumbar	23
Total number of pseudarthrosis intervals.....			63

Hemifusion: In forty-five operations, iliac strips of bone were placed entirely on one side of the spinous processes, in contact with the underlying laminae. Of these, pseudarthrosis developed in 31.1 per cent. The authors had expected to find this method of fusion more satisfactory in this area of the spine.

Arthrodesis of Only the Fourth to Fifth Lumbar Interspace

Arthrodesis of the single interval at the fourth lumbar vertebra was performed on six occasions for disc hernia. In three, the fusion had to be extended to the sacrum, and two other patients are still partially disabled with lumbosacral complaints.

Mortality

Although this summary is concerned mainly with the development of pseudarthrosis, the mortality is reported for the entire series. There were six deaths. Two resulted from shock, two from infection, one from nephritis with resulting anuria, and one from embolus. This represents a mortality rate of approximately 1 per cent. Transfusions have been administered routinely since 1942, starting with operation, and since that date shock has not been a problem.

STATISTICS REGARDING THE REPAIR OF PSEUDARTHROSIS

Of the 119 patients in whom pseudarthrosis developed, only thirty-five returned to the authors for repair. Many of the remainder had symptoms insufficient to demand surgical treatment. A few refused further care or went elsewhere for repair. Forty-three repairs were done on these thirty-five patients (Table IV). In four instances, two repairs were carried out on each patient; and in two instances, three repairs were done. Of the twenty-nine others, each had one attempt at repair. The average time interval from the original spine fusion to repair of the pseudarthrosis was 24.2 months. The average length of follow-up has been 44.9 months. The average age of the patients was 35.6 years. No case was accepted for study until at least a year after operation or unless the result had been checked by biplane bending roentgenograms which were superimposed. Since in no instance in the whole series have we seen a spine fusion become solid later than eight months after operation, when checked by biplane bending roentgenograms, we have accepted results as regards pseudarthrosis as final after such a period, when so controlled. One death occurred in this series of patients operated upon for repair of pseudarthrosis. This death is the one previously reported as resulting from anuria due to nephritis.

Preoperative flexion roentgenograms in two planes have been required in all cases since 1940. Of thirty-one patients, on only one occasion did biplane bending roentgenograms fail to show that a pseudarthrosis was present. In twelve cases in which flat roent-

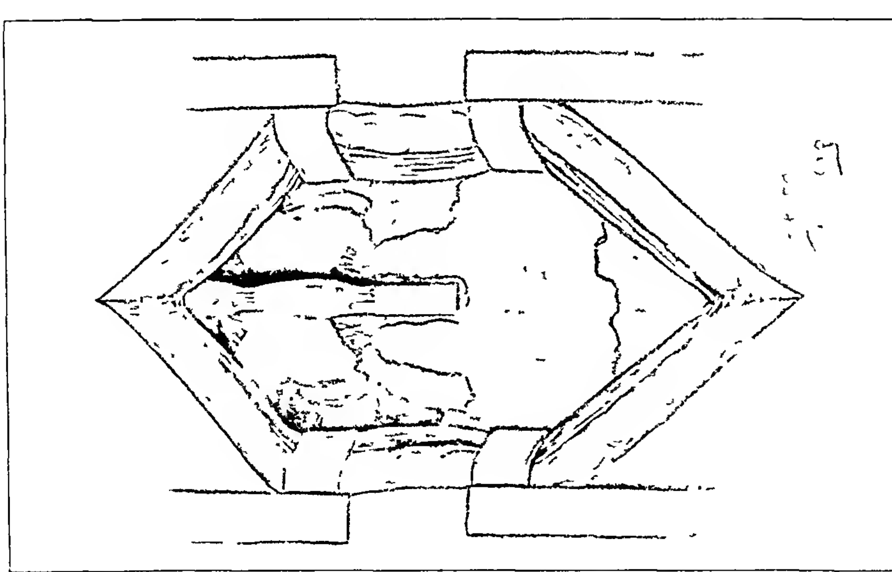

Fig. 3-A

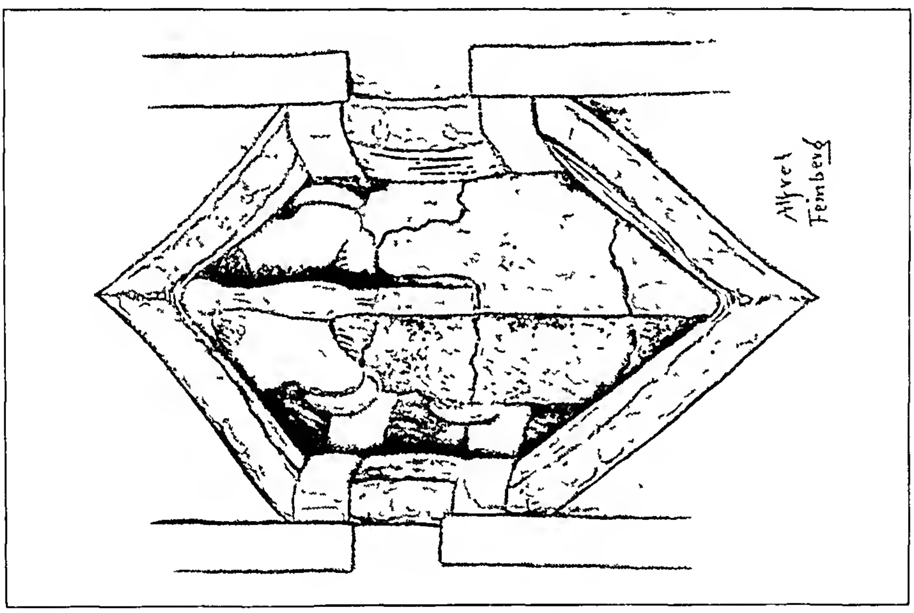

Fig. 3-B

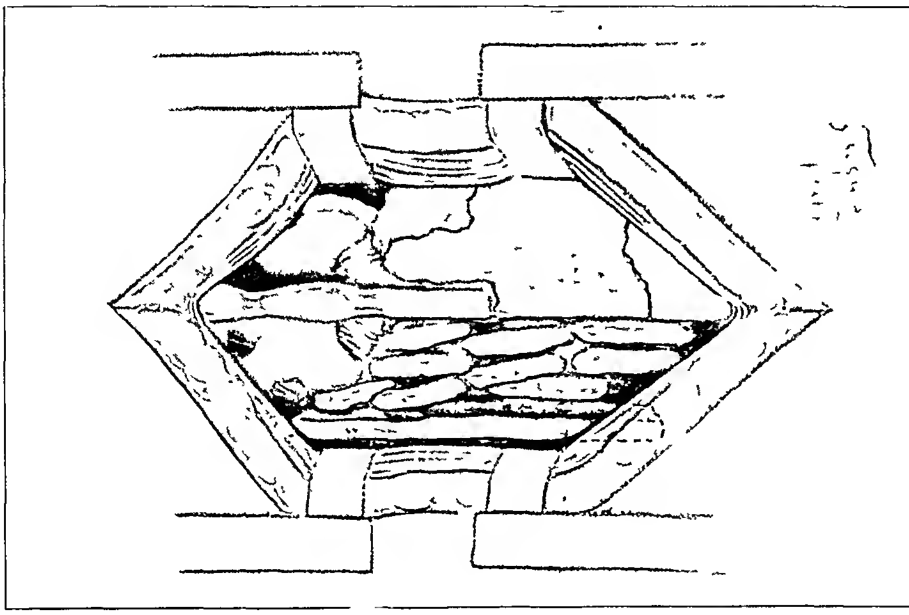

Fig. 3-C

Fig. 3-A: Two types of pseudarthrosis are shown,—the usual transverse type and the type occurring at the end of a clothespin graft.

Fig. 3-B: Repair of such pseudarthroses is carried out on one side only. Transverse processes and articular facets are exposed, and the site of previous fusion is denuded on its posterior surface only.

Fig. 3-C: A wide iliac strip is set vertically on the transverse processes outside the articular facets and in contact with them. Strip grafts of ilium are then placed over the dorsum of the previous fusion on one side, in the angle between the fusion and the vertically placed graft. The remainder of the previous fusion on the opposite side is not even exposed, being shown in the illustration only for clarity. It is left alone for such support as the bony masses already provide.

TABLE VI

FAILURE OF PSEUDARTHROSIS REPAIR ACCORDING TO ORIGINAL DIAGNOSIS

Diagnosis	No of Operations	No. of Persisting Pseudarthroses	Failures (*Per cent.*)
Posterior herniation of intervertebral disc	9	4	44 4
Lumbosacral strain	20	6	30 0
Tuberculosis. .	8	2	25 0
Spondylolisthesis	4	1	25 0
Arthritis	2	0	0

genograms alone were taken, four or 33.3 per cent. failed to show pseudarthroses which were found later at operation. Furthermore, we have on many occasions seen apparently solid fusion in lateral flexion and extension roentgenograms, whereas anteroposterior lateral-bending roentgenograms showed pseudarthrosis to exist. It is the authors' firm conviction that all cases of fusion in the lumbosacral spine must be checked with *biplane* bending roentgenograms for satisfactory statistics to be secured.

Location of Pseudarthrosis

The forty-three operations for repair of pseudarthrosis covered sixty-three spinal intervals with failure of fusion; in other words, more than one pseudarthrosis was found at operation in several of the patients. Most of the pseudarthroses were located at the fourth lumbar interspace; the next most frequent number were at the fifth lumbar interval (Table V). The great number found at these two intervals is accounted for by the fact that most of the spine fusions crossed them. Although all operations crossed the fifth lumbar interspace, the greatest number of pseudarthroses were at the fourth lumbar. This may be because of the relative instability of the fourth lumbar as compared with the fifth lumbar. In the twenty-five instances in which a single pseudarthrosis was found, six or 24 per cent. failed of repair. Of the twelve patients with two pseudarthroses each, only 50 per cent. success was obtained at repair. In the remaining six patients with more than two pseudarthroses, the percentage of success was even lower. Repair of pseudarthrosis is appreciably more difficult than original fusion.

Success of Pseudarthrosis Repair as Based upon Original Diagnosis

Nine repairs of pseudarthrosis were performed in which the original diagnosis was posterior herniation of the intervertebral disc (Table VI). There was failure to secure ankylosis in 44.4 per cent. Where lumbosacral strain had been the original diagnosis, there were twenty cases with 30 per cent. of pseudarthroses developing after attempted repair. Among eight patients with an original diagnosis of tuberculosis, there was 25 per cent. failure of repair. Spondylolisthesis patients showed 25 per cent. failure of refusion. Two arthritic patients who had pseudarthroses repaired both secured solid ankylosis.

TABLE VII

RELATION OF FAILURE OF PSEUDARTHROSIS REPAIR TO TYPE OF OPERATION USED

Technique	No. of Operations	Failures	
		No.	Per cent.
Iliac strips. . . .	18	4	22 2
Double clothespin graft.	14	4	28 6
New procedure	7	2	28 6
Local bone.	4	3	75 0

Relation of Failure of Pseudarthrosis Repair to Type of Operation

In eighteen patients, iliac strips were used on both sides of the mid-line, with four failures or 22.2 per cent. (Table VII). These were the simpler cases. When the clothespin or buttress graft was reapplied, together with iliac strips, there were fourteen cases with four failures, a percentage of 28.6. A new procedure was developed for the more difficult cases (multiple pseudarthroses), in an attempt to reduce the percentage of failure. By this type of procedure, seven cases have been treated with two failures (28.6 per cent.). Since these were the cases with two or more pseudarthrosis intervals each, it can be seen that the reduction from 50 per cent. failure to 28.6 per cent. failure may represent a real advance. This operation will be described herewith. Local bone was used on four occasions with three failures (75 per cent.). These cases were treated many years ago, before it had become routine to add iliac or other bone strips.

In three patients a typical herniation of intervertebral-disc material was removed from beneath a pseudarthrosis.

Postoperative Care

Plaster jackets were used postoperatively for five months or more in twenty instances. Of these, new pseudarthroses developed in seven or 35 per cent. In view of this percentage of new pseudarthroses, we feel that the jacket may be dispensed with and a reinforced lumbosacral corset used.

Causes for Development of Pseudarthrosis

These cases have been explored carefully. Certain outstanding causes of failure of fusion were noted. In all but ten instances, there seemed to be a definite factor which one could recognize for each particular case. In thirteen instances it was clearly evident that an inadequate amount of bone had been used for grafting material. In five instances the pseudarthrosis could be definitely ascribed to the use of solid, heavy tibial bone, not supported by iliac bone or other fine strip grafts. Infection at the original operation for spine fusion, draining sinuses associated with tuberculosis, hematomata resulting from the original fusion, et cetera, occurred in ten instances. In five instances the solid spine fusion (as determined previously by biplane bending roentgenograms) had been fractured. In two of these cases the spinous process at the upper end of a clothespin graft had been torn loose from the underlying laminae, and in three the fusion had been broken directly across. Crossing of previous laminal defects seemed to be the basis of pseudarthrosis in ten instances. Of these ten cases, new pseudarthroses developed in five on attempted repair, or a failure of 50 per cent.

NEW TYPE OF REPAIR

A new type of operative procedure has been used for the few more difficult cases of pseudarthrosis (Figs. 3-A, 3-B, and 3-C). It consists essentially in denuding the laminae and the lateral margins of the articular processes, with extension of the dissection to the bases of the transverse processes on one side only (hemifusion). The medial portion of the transverse process is likewise denuded. A thin, wide flap is removed from the outer cortex of the ilium and implanted vertically on the transverse processes. Iliac strips are then placed over the denuded posterior elements of the involved vertebrae themselves, the angle between the implanted massive iliac graft and the mid-line being filled in. Wandering of the chips is prevented by the laterally placed large iliac graft. Furthermore, contact is made with the transverse processes and the outer surfaces of the articular facets, as well as across the previous spine fusion on one side. When this form of repair is used, only one side of the spinal area is dissected and one half of the pseudarthrosis area is seen. The remaining previous bony masses on the opposite side are left intact for such stability as they may already produce.

Although percentages have been indicated, too few of these operations have been done for a final estimation of their efficacy.

CONCLUSIONS

1. The percentage of pseudarthrosis developing in spine-fusion operations in the lumbosacral region may be reduced by an adequate amount of bone of good texture, firmly implanted and free from infection.

2. The possibility of pseudarthrosis should be discussed with the patient before operation in every instance, so that he is forewarned, and so that consent for repair may more readily be obtained, when necessary.

3. One should avoid covering any greater number of spinal intervals than are absolutely essential in performing a fusion at the lumbosacral juncture, but the fusion should always extend to and include the sacrum.

4. For statistical and practical purposes, it is useless to report a series of spine fusions at the lumbosacral juncture without control of the series by biplane roentgenograms, taken with the patient in flexion and extension, and with right and left bends. The roentgenograms should then be accurately superimposed. Furthermore, even with such roentgenograms, a few instances of pseudarthrosis in any series will fail to be recognized.

Note: The authors wish to acknowledge the assistance, in the compilation of these statistics, of Kazuo Yanagisawa, M.D., and Alfonso Della Pietra, M.D.

1. Bosworth, D. M.: Clothespin Graft of the Spine for Spondylolisthesis and Laminal Defects. Am. J. Surg., 67: 61–67, 1945.

DISCUSSION

Dr. Joseph S. Barr, Boston, Massachusetts: Dr. Cleveland and his associates have presented a most interesting paper on a timely and important subject. Spine fusion is an important procedure in the armamentarium of the orthopaedic surgeon. It is necessary that we re-examine all of our patients who have had fusion to determine what the percentage of failures is and to take such steps as will enable us to lower the percentage of failures. Dr. Cleveland has stated that the major causes of failure of fusion are: (1) the use of an inadequate amount of bone, (2) infection, and (3) fracture of the graft. To this list of important factors I would like to add some additional points.

1. Complete fixation of the segments to be fused, so that all motion is obliterated, should be our aim. Fixation by external means, such as plaster casts and shells and prolonged bed rest, is demonstrably ineffective, for varying amounts of motion occur, no matter what type of apparatus is used. The double clothespin graft, or H graft as I prefer to call it, is a very effective means of immediate internal fixation, and I think that where it can be used, it represents a definite advance in technique.

2. The use of screws across the facets and bone plates between spinous processes has become popular in certain clinics. There are disadvantages to the use of metals which may outweigh their advantages.

I agree with the authors' conclusions that, if the fourth lumbar space is fused, the fifth lumbar must be included. Dr. Cleveland has omitted reference to what, if anything, he does to the articular facets at the time of fusion. This is a difficult question. They can be left untouched. They can be cut across and bone grafts laid over them. They can be curetted and excised or a key graft placed across the facet, as advocated by McBride. There is room for further study of this problem. Theoretically, at least, if one succeeds in obtaining fusion of the articular facets, motion between the involved segments will be obliterated. Fractures through the neural arches may occur, however, unless additional bone is used.

I believe that careful preparation of the bed and of the facets, as advocated by Hibbs, plus the use of an H graft with additional cancellous bone from the ilium, is the most satisfactory method of fusion available today.

No matter what method is used, biplane bending roentgenograms, taken after one year, will reveal pseudarthrosis in an unpleasantly high percentage of cases. Repair of the pseudarthrosis is unnecessary in about 50 per cent. of the cases, as clinically they are asymptomatic.

I find myself in complete agreement with the authors in practically all of their major premises, and wish to congratulate them again on an excellent paper.

Dr. Eugene M. Regen, Nashville, Tennessee: You have heard another typical Cleveland, Bosworth, and Thompson report. The tremendous value and significance of this analysis cannot be appreciated in the short time they have had to present their findings, and I would urge their careful examination in less

hurried moments. I could profitably emphasize many of their conclusions, but the virtues of their paper ar so obvious that I shall confine myself to some few questions that have arisen as I read this report.

1. A curve to indicate the incidence of pseudarthrosis year by year, as new operative procedures de veloped and as the surgeons improved their technique, might be enlightening.

2. No report was made on the type of postoperative care following the original fusion. It is my opinion that there now exists over the country a distinct trend toward inadequate postoperative fixation and bed rest following spine fusion. One wonders whether the prospect of a relatively short period of bed confinement may serve as an inducement for the patient to accept this major operative procedure. Since the incidence of pseudarthrosis varies inversely with the security of the fifth, fourth, and third lumbar vertebrae to the pelvis and their distance from it, I believe that this would indicate the use of adequate plaster fixation and bed confinement for from two to three months after the operation.

3. In discussing the causes of pseudarthrosis, the authors did not mention the possible influence of spinal fluid escaping after the accidental opening of the dura. All of you who have explored the spinal canal know that this is not an infrequent occurrence.

4. The authors have proved conclusively the value of biplane bending roentgenograms. They require the accurate superimposition of corresponding points on the roentgenographic films, but it is a fact that fibrous fixation alone can be secure enough to prevent the detection of motion at a given vertebral joint by the method of examination they describe.

5. The paper states that the relief of symptoms is directly proportional to the length of successful fusion above the sacrum, but the authors did not emphasize the danger of limiting a working man's usefulness by stiffening too many of his lumbar joints.

6. Since the vast majority of lumbosacral operations are performed for mechanical disorders, with or without nerve-root compression, I believe one should universally perform the fusion from the sacrum to the fourth lumbar vertebra only, unless there is a distinct indication to go higher.

7. The necessary period of postoperative fixation is usually followed by temporary stiffening of joints above the site of fusion. I routinely employ a set of simple exercises, begun three months after operation, which have materially shortened convalescence. These exercises mobilize the joints above the site of fusion, and greatly strengthen the glutaeus maximus and anterior abdominal muscles.

8. My experience does not compare with that of the authors in number of cases. My postoperative follow-up does not meet their criteria, but observation of my own patients has not revealed pseudarthrosis to be noticeably prevalent. I feel reasonably sure that it is well under the 20 per cent. which the authors report in their series.

9. Finally, even though a painful pseudarthrosis does exist, the symptoms can often be largely, if not entirely, relieved, and a secondary operation can be avoided by postural exercises which tend to remove the stress and strain from the site of abnormal joint irritation.

Dr. Alan DeForest Smith, New York, N. Y.: It has been the habit at the New York Orthopaedic Hospital to make periodic surveys of the results of fusion operations. The results in the lumbosacral cases have been comparable to those which Dr. Cleveland reported.

Our first survey showed 12 per cent. of failures at the fifth lumbar, and 20 to 30 per cent. between the fourth and fifth lumbar; and that has continued, although we have reduced the percentage to 8 at the lumbosacral joint. The failures between the fourth and fifth lumbar vertebrae still remain high. That seems to be the critical point. Internal fixation has not helped. In any case in which fusion extends above the fifth lumbar, I believe that a double spica should be used, and the patient should be confined to bed for at least eight weeks.

I was interested to see the results with the clothespin graft, and to note that they showed no difference from those cases in which other methods were used.

Dr. D. M. Bosworth (closing): This study was attended by a great deal of difficulty. We tried to divorce entirely the question of pseudarthrosis from that of recovery on a symptomatic basis.

All these fusions were done by three surgeons only. They were a control series, not done by residents, but accurately performed by careful, well-trained men. They were performed in six hospitals, so there was no variation in incidence of complications based on the type of hospital used.

The postoperative care in most of the cases has been two and one-half to three weeks of bed rest, and thereafter a lumbosacral belt reinforced with light steel. The biplane bending roentgenogram was established for the purpose of follow-up accuracy. A few cases of pseudarthrosis will be unrecognized, even with biplane bending roentgenograms. In our series, in only one instance was pseudarthrosis unrecognized by such roentgenograms. Patients securing solid fusion become free of back disability, as a rule. They do not notice loss of spine motion clinically. As to the tight graft, I know of one H graft which was placed too tightly by the surgeon.

As to the question of removal of the articular facet, the facets were usually left intact in our cases. If a large series were run without débridement of the articular facet, and the percentage remained the same as with débridement of the articular facet, we would feel that that particular procedure would not be necessary.

CARTILAGINOUS-CUP ARTHROPLASTY IN UNUNITED FRACTURES OF THE NECK OF THE FEMUR *

BY JOHN ROYAL MOORE, M.D., PHILADELPHIA, PENNSYLVANIA

From Temple University Hospital, Philadelphia

Ununited fractures of the neck of the femur have been less frequent since the revival : internal fixation of acute fractures of the femoral neck, in 1931, by Smith-Petersen and is associates. In a recent review of 300 fractures of the femoral neck, Boyd and George eport union in 86.5 per cent. and non-union in 13.5 per cent. However, ununited fractures f the neck of the femur are a greater problem today, since the revival of internal fixation, ue to the fact that the head of the femur and the trochanteric area are often irreparably amaged by the internal-fixation elements themselves. It is not unusual to encounter rge defects in the trochanteric area and in the head of the femur, and in many instances 1 the cartilage of the head and the acetabulum, which have resulted from nails, screws, r various types of pins. The employment of the bone graft in ununited fractures of the eck of the femur, as advocated by Albee and others, which was frequently used in the te 1920's and the early 1930's, is usually contra-indicated, principally because of the tructural defects already referred to. Aseptic necrosis of the head continues to persist ith slight, if any, reduction in its frequency, in spite of internal fixation. Absorption of he neck of the femur (both the shaft and the head fragment) is often more pronounced han formerly, due either to failure to recognize the non-union early or to persistent reention of the internal-fixation apparatus in the hope that, by a miracle, union may occur.

All of these factors play an extremely important part in the selection of the procedure o be employed in the treatment of ununited fractures of the femoral neck. The writer livides ununited fractures of the neck of the femur into three classes:

Class I: Non-union with a viable head and well-preserved neck fragments.

Class II: Non-union with a viable head and complete, or nearly complete, absorption of one or both neck fragments.

Class III: Non-union with absorption of the neck fragments and a devitalized head.

The bone graft, recommended by Albee, or the bone graft combined with internal pin fixation, recommended by Gallie, and the osteotomies suggested by Pauwels, Leadbetter, Dickson, Schanz, and McMurray, are especially suited for cases in Class I. The reconstruction operations of Brackett, Luck, and Magnuson, and similar procedures, are particularly indicated for fractures in Class II. The reconstruction procedures advocated by Whitman, Albee, Colonna, Lorenz, Smith-Petersen, Wilson, and others may be employed in the fractures of Class I, but seem particularly indicated in Class II or Class III, where loss of the neck and a "dead" head are present. All of these operative procedures are well known, and time and space do not permit a detailed description of the technique of the operations or a discussion of their relative merits.

The cartilaginous-cup arthroplasty was devised by the writer in 1938, and should be properly regarded as a modification of the Brackett operation. Wagner, in 1929, advocated removing the head of the femur, reaming out the head, and fitting it to the neck of the femur, thus restricting its use to those cases in which the distal fragment of the neck persisted.

TECHNIQUE

Briefly, the cartilaginous-cup arthroplasty consists in removing the femoral head and reaming out the osseous portion until only a cartilaginous cup with a very thin layer of

* Read at the Annual Meeting of The American Orthopaedic Association, Hot Springs, Virginia, June 28, 1947.

bone (one-eighth of an inch or less in thickness) remains. The cup then readily transmits light (Fig. 4,*b*). A small section of the trochanter is elevated and reflected with its attachment to the glutaeus medius. The end of the femur is then carefully rounded off with a cup reamer and the cartilaginous cup is fitted to it. The femur with its cartilaginous cup is then returned to the acetabulum, and the greater trochanter is reattached to the lateral aspect of the shaft, two or three inches below the cup level. (Figures 1 to 6, inclusive, are illustrative of the technique.) The wound is carefully closed in layers, beginning with the capsule and following with the vastus lateralis and glutaeus medius layer, then the fascia lata, the subcutaneous tissue, and the skin. A double hip spica, extending from the ankle to the nipple line on the side being operated upon and from the knee to the nipple line on the other side, is applied. The extremity operated upon is in maximum abduction, usually from 60 to 80 degrees, with the patella pointing straight up. A minimum of 60 degrees of abduction is essential. Occasionally an adductor tenotomy is required to obtain the desired abduction.

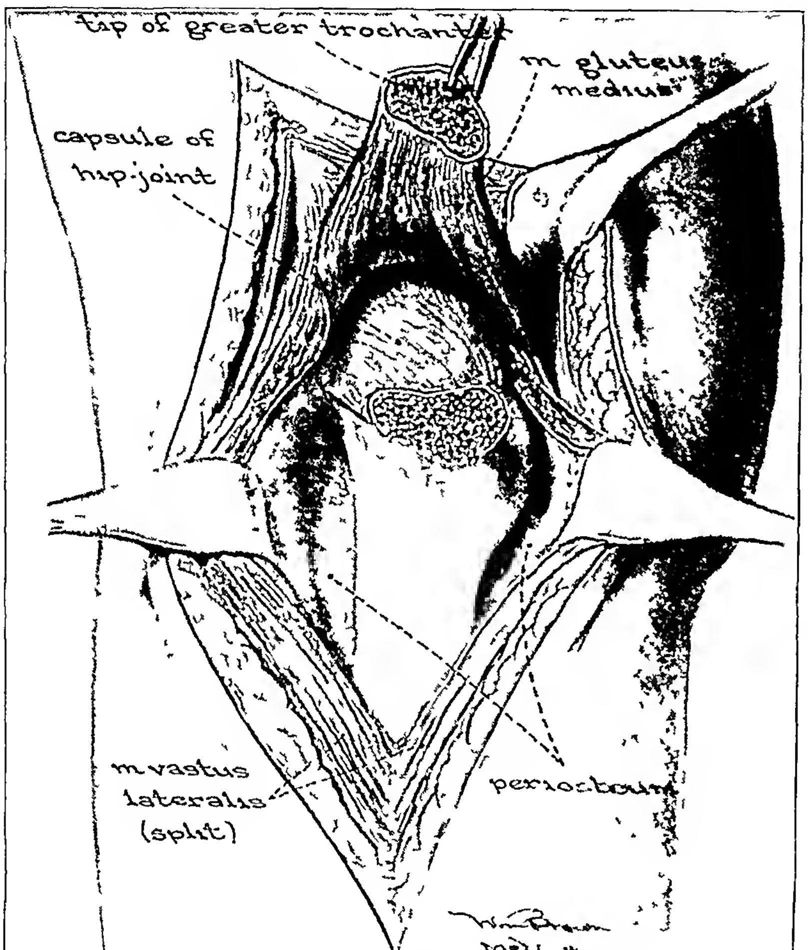

Fig. 1

The approach to the hip used in the cartilaginous-cup arthroplasty (not original).

Certain points should be emphasized in carrying out this procedure. Complete hemostasis, clamping and tying all vessels to prevent free bleeding (except from bony areas), is essential. The cup must be fitted snugly. It should be placed accurately on the end of the femur, neither in valgus nor in varus, and with neither anterior nor posterior tilting. Its position should be maintained by wide abduction; this is accomplished by abducting the femur until firm resistance is met. A double spica is essential to complete the immobilization. The foot on the side operated upon need not be included. The trochanter with its gluteal attachments must be reattached in order to ensure abduction power. It should be reattached securely, preferably with a screw, in order that early union of the trochanter and the shaft may be obtained. Closure must be done with extreme care to avoid hematoma. It is very important to ream the femoral head out thoroughly before the proximal end of the femur is rounded off, to prevent a small femoral fragment. The cup must fit very tightly; otherwise it will slip off (Case 7).

POSTOPERATIVE CARE

Movement of the ankle, foot, and knee on the side not enclosed in the cast is begun after recovery from the anaesthesia (spinal anaesthesia is employed in all cases), and is carried out hourly during waking hours. Deep breathing, likewise, is done at hourly

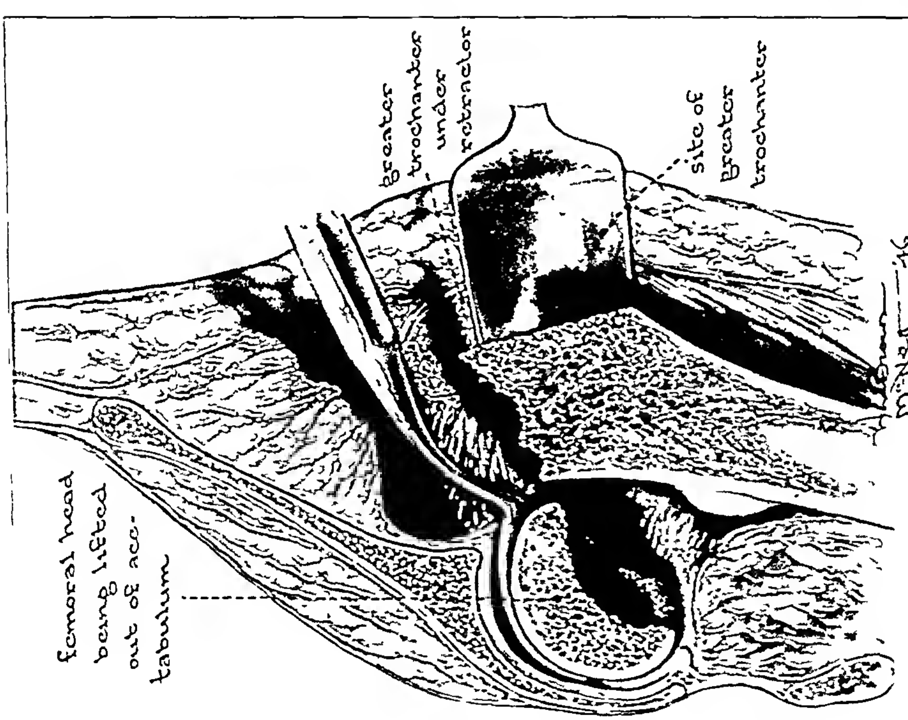

Fig. 2

Sketch of a sagittal section through the hip, illustrating removal of the head

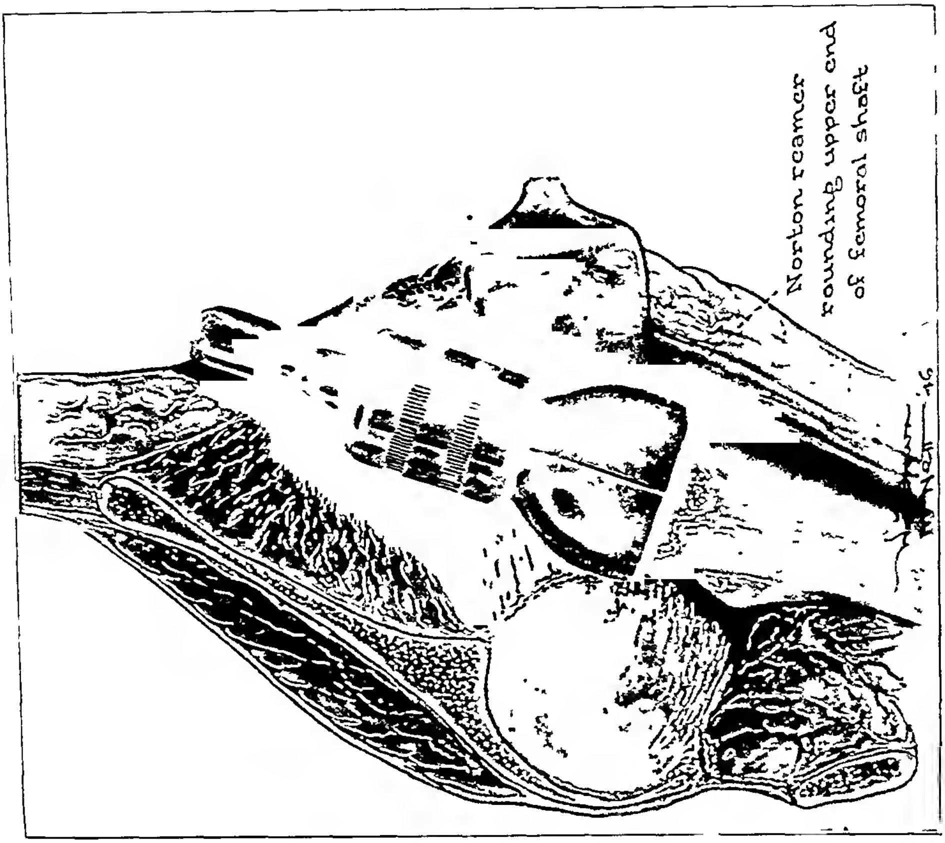

Fig. 3

Preparation of the trochanteric area of the femur with reamer.

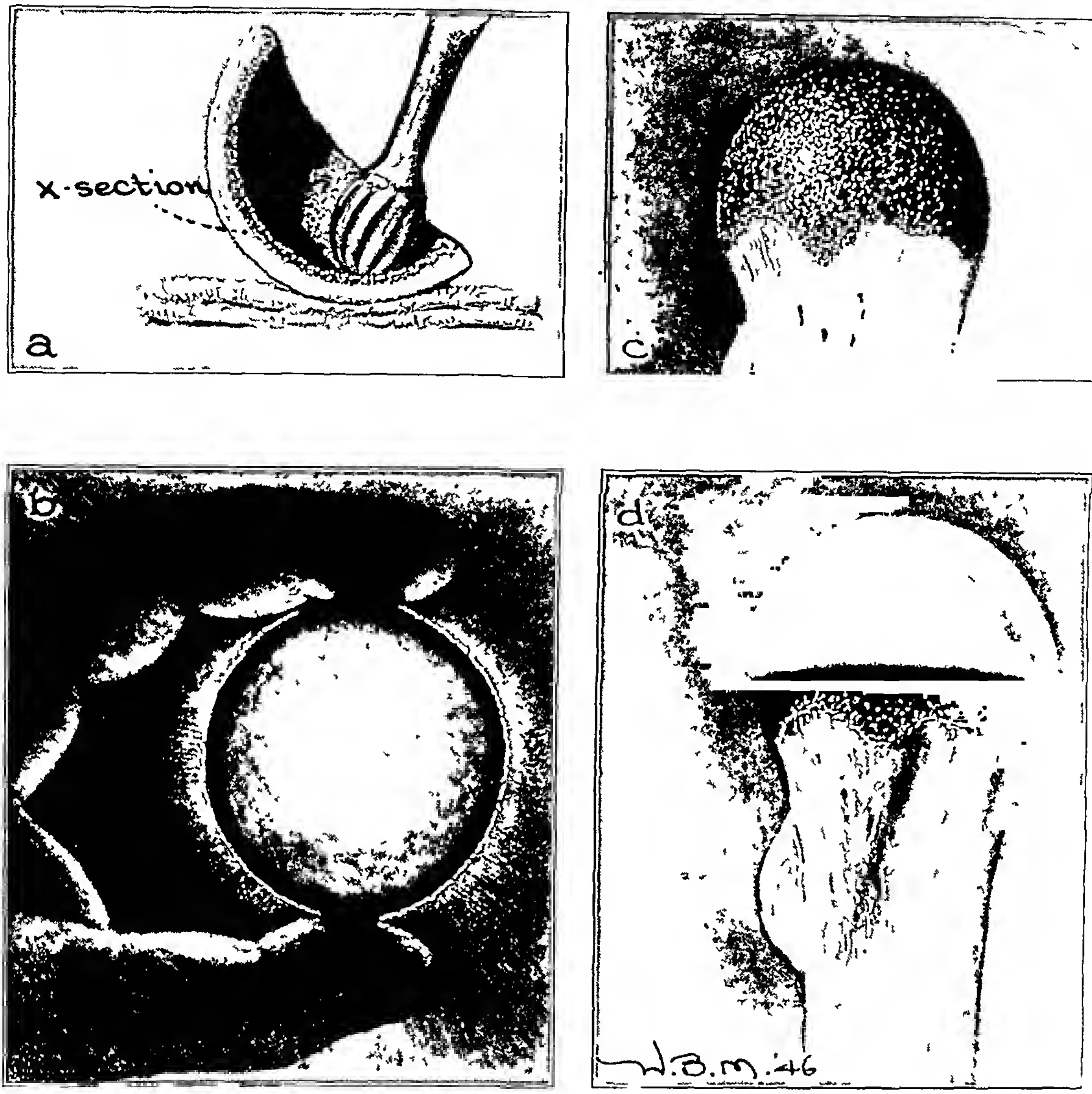

FIG. 4

Illustrates the preparation of the head, the light test, and the fitting of the head on the femur.

intervals. The patient is turned every two hours during the day and every four hours during the night. On the twenty-eighth day the back half of the plaster, on the side on which the knee is enclosed in the cast, is cut and knee exercises are done at hourly intervals until flexion of 90 degrees or better is obtained. This usually requires one or two weeks. On the forty-second day (six weeks), the thigh which was not operated upon is released. The hip spica on the side operated upon is removed at the beginning of the eighth week, and balanced traction is applied in the line of abduction. The extremity is gradually brought down to approach the neutral position. The patella must be straight up so as to avoid any external-rotation deformity. Active flexion, extension, and rotation exercises are employed during the traction period. Weight-bearing is permitted at the end of the tenth week.

By the end of the sixth month the patient usually has approximately 80 degrees of flexion, 30 degrees of abduction, 5 to 10 degrees of adduction, and 180 degrees of extension This motion increases gradually up to one year. In case of pain in the hip or the knee on the side which has been operated upon, or a tendency to external rotation, the patient is confined to bed with a five-pound to ten-pound weight and pulley traction, until the discomfort has disappeared. A moderate abduction deformity occasionally persists as long as six months. Three centimeters of shortening may occur, depending upon the structure of the upper end of the femur. This must be rounded off until a healthy bone surface

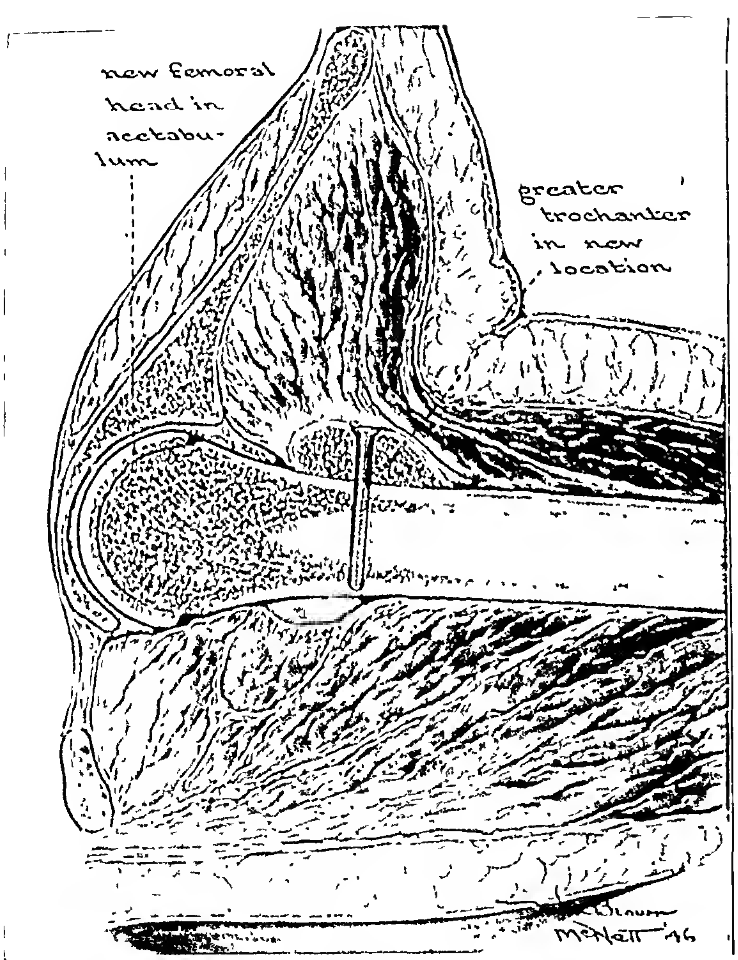

FIG. 5

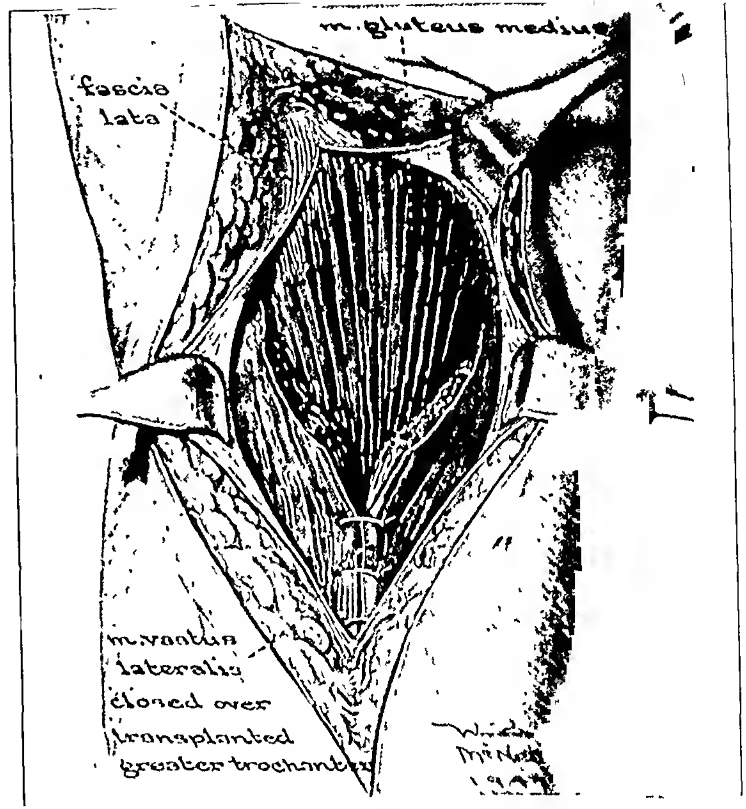

FIG. 6

Fig. 5: Shows the cartilaginous cup properly placed on the end of the femur and inserted within the acetabulum. The fragment of the trochanter is attached to the femur with a Vitallium screw. (Note that the shaft of the femur is in wide abduction.)

Fig. 6: The greater trochanter has been attached to the shaft of the femur. The vastus lateralis is approximated and sewed to the soft parts overlying the trochanter and to the muscle sheath of the gluteus medius. (This is similar to the technique of Colonna.)

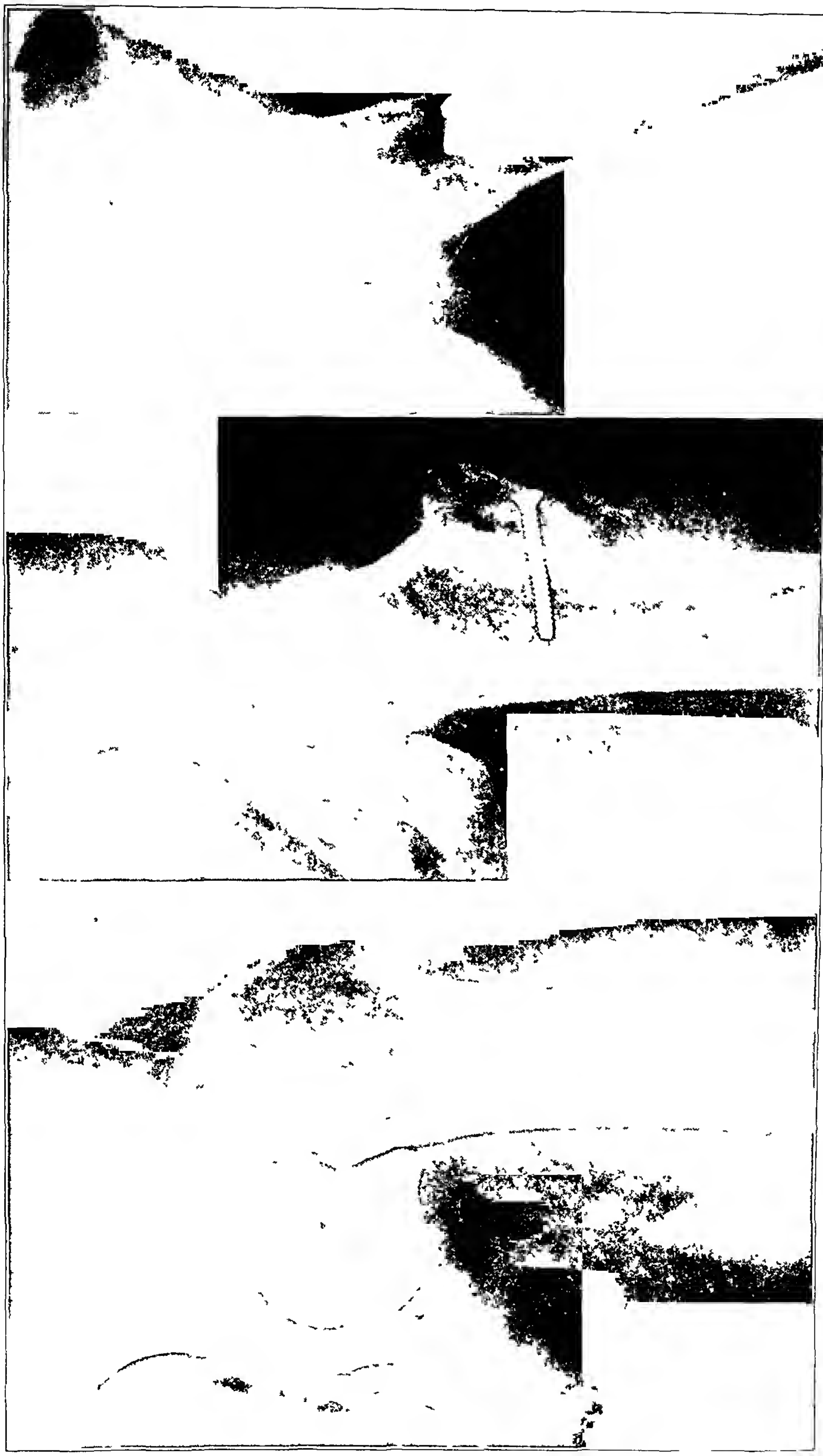

Fig. 7-A Fig. 7-B Fig. 7-C

Fig. 7-A: A. J. Ununited fracture of the neck of the femur (January 24, 1946).
Figs. 7-B and 7-C: Anteroposterior and lateral views of cartilaginous cup after fifteen months (May 5, 1947).

or contact with the head is encountered, thus causing the shortening. Shortening of less than two centimeters is not compensated for by an elevation of the heel, as the tilt of the pelvis compensates for the loss of the neck angle and maintains the acetabulum in a favorably tilted position, thus offering the best assurance of stability in this type of procedure.

RESULTS

The cartilaginous-cup arthroplasty has been performed in nineteen cases in Class II and Class III, from 1938 until June 1947. Eleven of the nineteen cases have been followed from one to nine years.

The majority of the patients were women, ranging in age from forty-four to seventy-seven years. Nine of the cases are considered to show excellent results. M. S. (Case 4) is considered to have had a fair result, in spite of the slight pain and the continued use of a cane, because he is happy and contented, and leads a normal life. Y. W. (Case 7) is regarded as a poor result, even though pain is very slight when a cane is employed. The patient works daily and earns her own living. Shortening averaged one to three centimeters, the majority of patients having two centimeters or less. The characteristic findings in early and late cases are illustrated in Figures 7-A through 10-C.

The majority of the patients complained of mild stiffness when they arose in the morning or after prolonged sitting. This disappeared after activity and, although regarded skeptically as an early sign of degenerative arthritis, it has offered no problem to date in any of the patients in the group.

COMPLICATIONS

Among the nineteen cases reviewed, there were three deaths. One patient, P. G. H., died twenty-one days after operation, and a pulmonary embolism was found at post-

Fig. 8-A Fig. 8-B

Anteroposterior and lateral views of cartilaginous cup, five months after operation.

FIG. 9-A FIG. 9-B FIG. 9-C

Fig. 9-A: E. W. Ununited fracture of the neck of the femur (December 19, 1944).
Figs. 9-B and 9-C: Anteroposterior and lateral views of cartilaginous cup, twenty-five months after operation (April 29, 1947). This is one of the early cases, and an attempt was made to sew the trochanter to the underlying soft parts. Note marked improvement in this regard in the more recent cases, as shown in Figs. 7-A, 7-B, and 7-C, and in Figs. 8-A and 8-B.

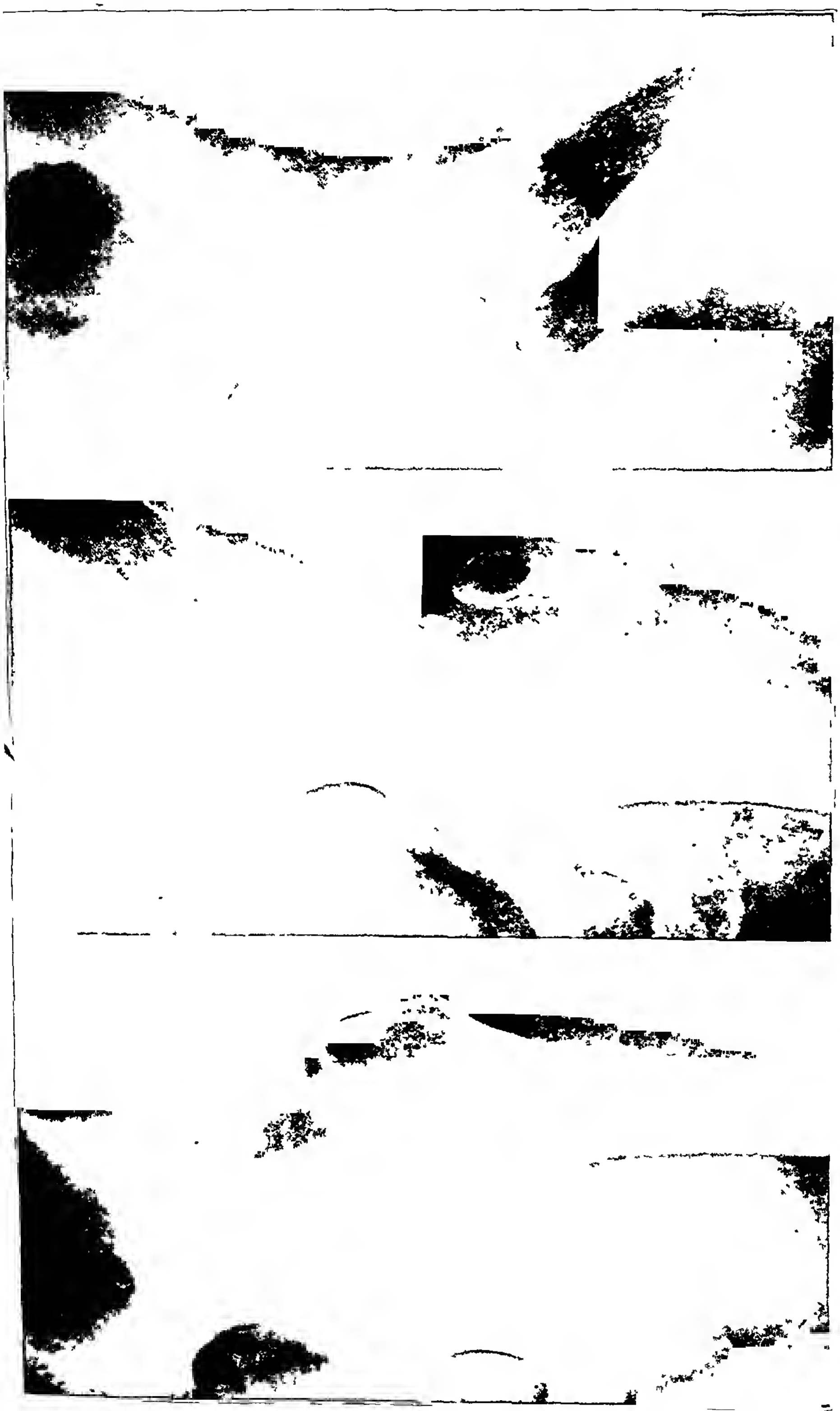

Fig. 10-A Fig. 10-B Fig. 10-C

Fig. 10-A: A. M. Ununited fracture of the neck of the femur (January 5, 1938).
Figs. 10-B and 10-C: Anteroposterior and lateral views of cartilaginous cup (July 26, 1940). In this early cartilaginous-cup arthroplasty, the trochanter was poorly attached (sewed in position). The end result was excellent (see Tables I, II, and III and Figs. 10-D and 10-E).

Fig. 10-D

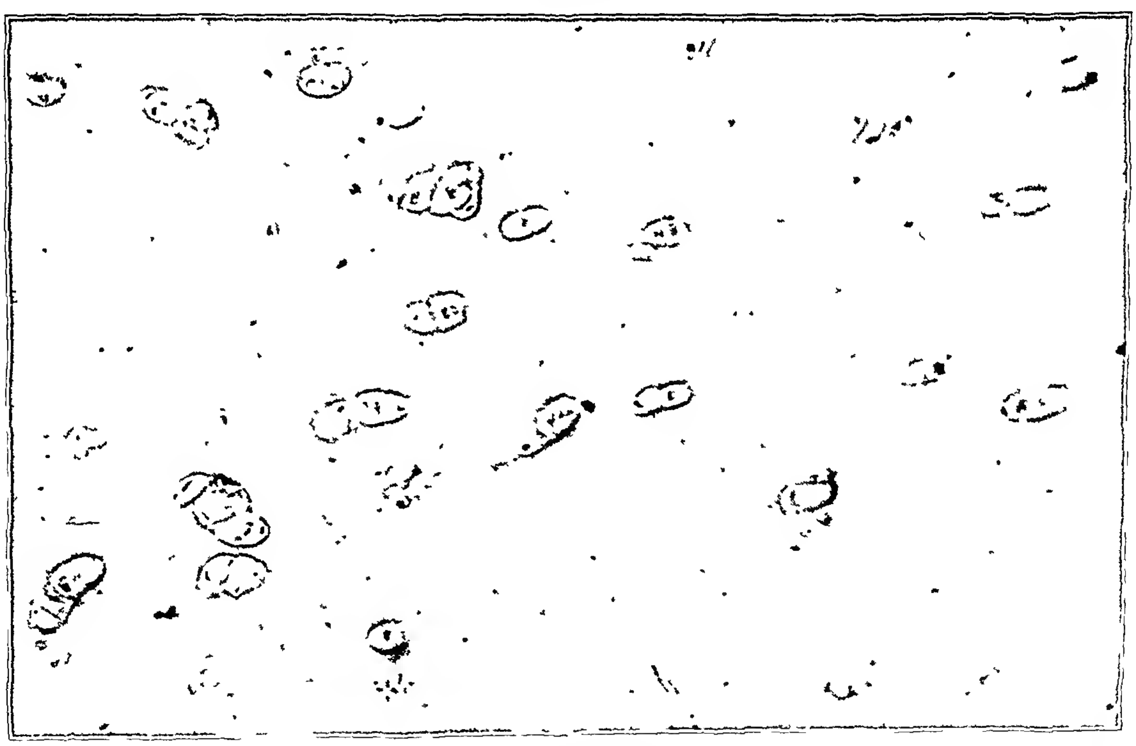

Fig. 10-E

Description of microscopic findings by E. E. Aegerter, M.D.: "One section was removed from the weight-bearing portion of the head of the femur. The articular surface of this bone is covered with a layer of cartilage, measuring approximately five millimeters in thickness. The hyaline matrix is homogeneous and appears to be normal in quality. There is a normal distribution of lacunae throughout this fragment of cartilage, and the cells within the lacunae appear to be normal. Directly beneath this cartilage is adult bone. There is no recognizable epiphyseal line and no evidence of new-bone formation. Between the rather coarse spicules are a few marrow cells, interspersed between considerable amounts of fat. Diagnosis: normal hyaline articular cartilage."

mortem examination. A second patient, S. T., died six weeks after operation, of a cerebral accident. The third patient, A. M., died nine years after a cartilaginous-cup arthroplasty,

TABLE I

FOLLOW-UP STUDIES AFTER OPERATION

Case	Patient	Sex	Age	Postoperative Period (*Years*)	Presence of Pain
1	A.M.	Female	63	9	None
2	A.F.	Female	72	7	None
3	A.R.	Female	72	7	None
4	M.S.	Male	63	6	Slight
5	A.McC.	Female	49	3	None
6	S.S.	Male	51	3	None
7	Y.W.	Female	53	3	Pain present
8	E.W.	Female	44	2	None
9	E.R.	Female	77	1	None
10	A.J.	Female	44	1	None
11	S.O.S.	Female	69	1	None

TABLE II

RANGE OF MOTION ONE YEAR AFTER OPERATION

Case	Extension-Flexion (*Degrees*)	Internal Rotation-External Rotation (*Degrees*)	Abduction-Adduction (*Degrees*)
1	190–110	30–30	45–45
2	180–90	10–10	30–15
3	180–90	30–30	45–45
4	180–90	30–10	20–10
5	180–80	30–10	15–30
6	180–90	20–20	30–20
7	195–110	10–30	45–30
8	190–110	30–30	30–30
9	180–60	10–45	30–0
10	180–90	30–10	20–10
11	180–90	15–30	30–20

of carcinomatosis. High-power and low-power microscopic sections of cartilage, taken from the head of the femur in this case, are shown in Figures 10-D and 10-E. A fourth patient, A. McC., has multiple sclerosis and has been confined to bed and to a walker since the second year after operation. There have been no operative deaths. In Y. W. (Case 7) the cartilaginous cup slipped off during the first three weeks, due to a poorly fitting head and lack of adequate abduction. This patient has a painful hip and degenerative arthritis, with a very thin joint line.

DISCUSSION

The cartilaginous-cup arthroplasty, first performed in 1938, differs from the Brackett operation, primarily, in that the head of the femur is converted fundamentally into a cartilaginous cup. The procedure was first performed with a good deal of trepidation, due primarily to the fact that the consensus of the investigators was that hyaline cartilage would not survive transplantation. A reasonable questioning of this impression was permissible because of the amazing restoration of the hip to practically normal motion, with a negative Trendelenburg sign and the absence of limp, and the appearance of a good joint line. The continuance of excellent joint motion and the absence of limp seemed to justify repetition of the procedure. This patient died in 1947, nine years after the operation,

and a section of the cartilage from the head of the femur was obtained (Figs. 10-D and 10-E). The pathologist's report * is as follows:

"A section, removed from the weight-bearing portion of the head of the femur, is covered with a layer of hyaline cartilage, measuring five millimeters in thickness. The hyaline matrix is homogeneous and appears

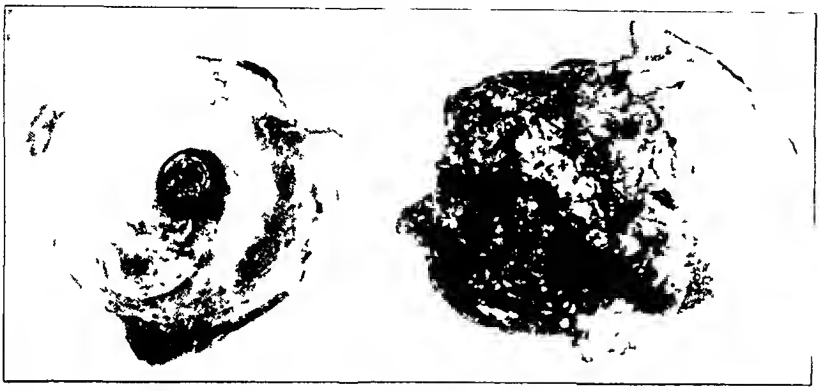

FIG. 11-A FIG. 11-B

Fig. 11-A: A cephalic view of a cartilaginous cup, three weeks old. (Patient died of pulmonary embolism.) The cartilage is blood-stained. It is firmly attached and could not be removed by vigorous twisting.

Fig. 11-B: A lateral view of the same cartilaginous cup. Note the blending of the cartilage with bone.

Fig. 12-A: Shows a six-week-old cartilaginous cup, attached to shaft. This was so firmly attached that manual manipulation could not pull it loose.

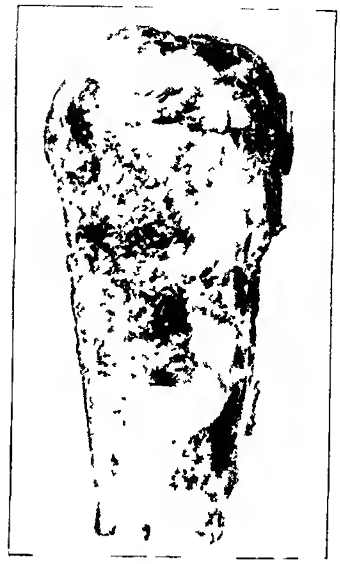

FIG. 12-A

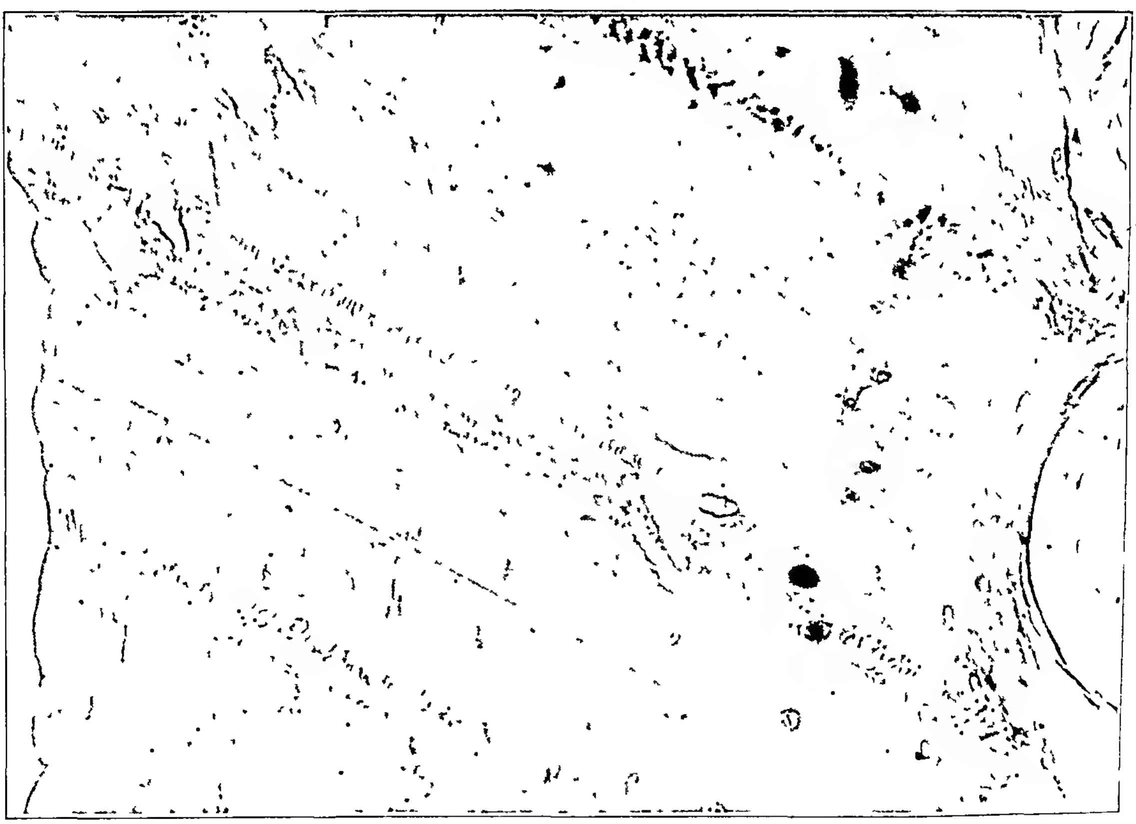

FIG. 12-B

to be normal in quality. There is a normal distribution of the lacunae throughout this fragment of cartilage, and the cells within the lacunae appear to be normal. Directly beneath this cartilage is normal adult bone. A section taken from the non-weight-bearing portion of the femoral head shows a layer of cartilage which is indistinguishable from that described above. Sections from the acetabular rim show the usual fibrillar cartilage with attachment of adult bony tissue. Diagnosis: normal hyaline cartilage."

* Made by E. E. Aegerter, M.D., Professor of Pathology, Temple University Medical School, Philadelphia, Pennsylvania.

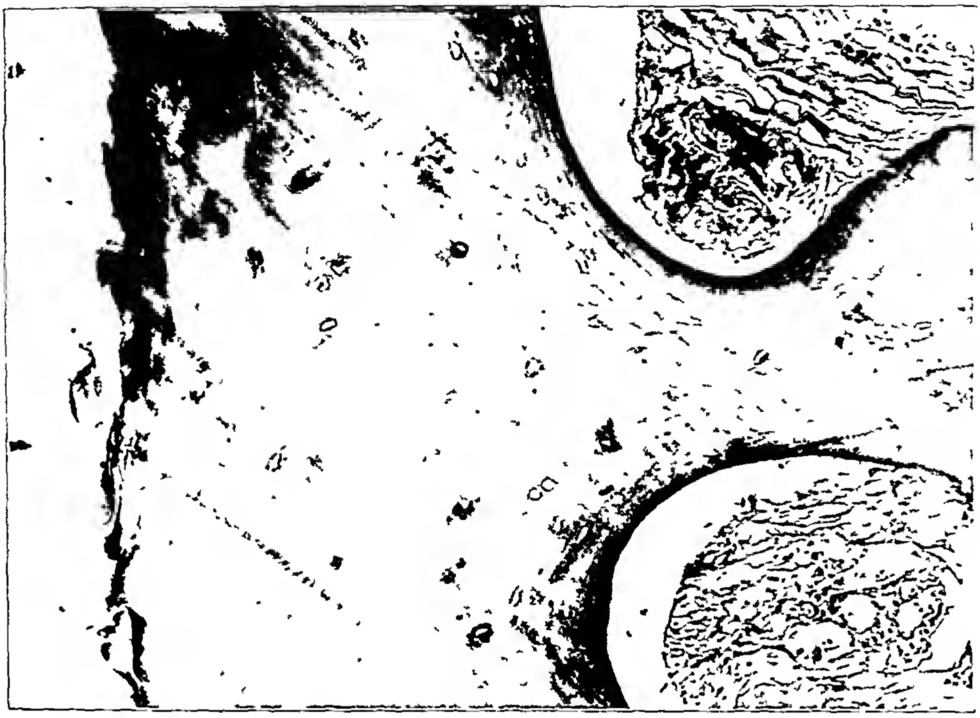

FIG. 12-C

FIG. 12-D

Figs. 12-B, 12-C, and 12-D. Description of microscopic findings by E. E. Aegerter, M.D.: "Sections from the surface of the head of this femur in the weight-bearing area show it to be covered by a layer of cartilage. The outer two-thirds of this tissue shows no evidence of living chondroblasts, but in the inner third lacunae are present and one can find viable cells. This suggests that the outer two-thirds had undergone cell death, but that the inner third has been preserved. Along the inner surface of this cartilaginous layer the bony spicules conform to the contours of the cartilage. . . . At one side of the section [illegible] of fibrous tissue and provisional bone, which appears to be arising from [illegible]r. One might conclude that this process has developed secondary to the implantation of the cartilage. Diagnosis: viable cartilage."

A second patient, P. G. H., died six weeks after operation. The head and neck o femur (Fig. 12-A) were obtained for study. From the description of the microscopi ings (Figs. 12-B, 12-C, and 12-D), it will be noted that the superficial cartilage dead, while the deep layers of cartilage are alive. Furthermore, "along the inner of this cartilaginous layer the bony spicules conform to the contours of the cartilage. would suggest that some osteogenesis has caused an arrangement of the bone lamel which is most efficient for stresses in this area. At one side there is a considerable amo of fibrous tissue and provisional bone, which appears to be arising from the under- tilaginous layer. One might conclude that this process has developed secondary to implantation of the cartil

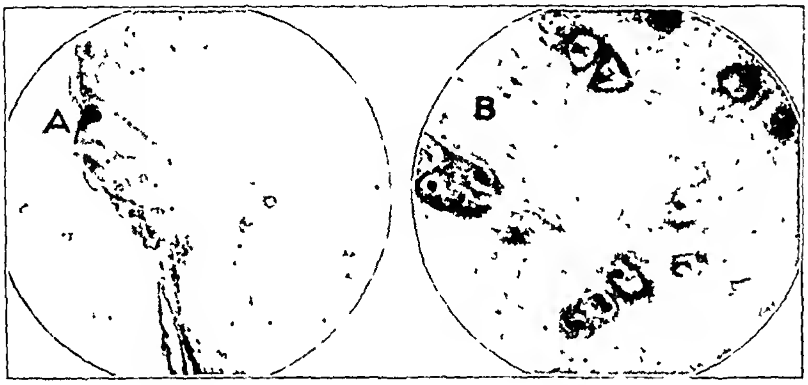

Fig. 13

Low-power microscopic section of a twenty-year-old autogenous rib-cartilage graft (used by John Staige Davis to repair a saddle depression in the nose). Graft became distorted and one-third of the transplant was removed twenty years later by Dr. Lyndon A. Peer. Note normal cartilage in old graft. (Reproduced, by permission of the American Medical Association, from *Archives of Otolaryngology*, *42*: 386, 1945.)

Figures 11-A and 11 represent a cartilaginous , three weeks old, taken from patient who died of pu nary embolism. The larg d fect present in the head w caused by the nail used in t internal fixation. The ea was securely attached a could not be pulled off b manual efforts. Unfortu nately, the microscopic sec tions were lost before the were read. The early bo attachment of the cartila to the head in this case an in that of P. G. H. (Figs 12-A to 12-D) is the basis for the relatively early mobilization in the after-care. There undoubtedly a long gap between the specimens observed nine years and six weeks, r spectively, after operation, but it is quite probable that the older case may have ha similar development.

The fact that normal hyaline cartilage was found in these cases does not prove, o course, that all of the other patients reported in this series have hyaline-cartilage regenera tion. However, the clinical and roentgenographic findings strongly suggest the possibilit that they are following a like course.

Lyndon Peer, in an article published in 1938, stated that Paul Bert, about 186 was probably the first to transplant hyaline cartilage. Bert concluded that cartilage graf retain their viability. Fischer, in 1882, reached the conclusion that cartilage grafts woul survive if transplanted with perichondrium. Loeb, in 1926, transplanted xiphoid cartilage wit perichondrium in the same guinea pig (autografts) and in different guinea pigs (homografts The autograft survived, with practically no reaction about the graft. The homograft survived but with a lymphocytic reaction which usually reached its peak at the end of twenty-one days Mannheim and Zypkin, in 1926, performed fifty experiments with autografts of hyaline cartilage, and concluded that the cartilage retained its specific structures in all cases and that autocartilaginous grafts formed good material for plastic repair. König, in 1896, was the first to use cartilaginous transplants in human beings. He employed cartilaginou grafts in the repair of laryngeal and tracheal cartilage defects. Von Mangoldt, in 1899, successfully transplanted costal cartilage to the nose. Most of the pioneer work in hyaline-cartilage transplantation has been performed by the otolaryngological and plastic surgeons. Davis, in 1917, and Gillies, in 1920, emphasized particularly the viability of hyaline-cartilage autogenous grafts and the practical value of these grafts to surgery. Lyndon Peer, from whose work the historical review is largely quoted, presented, in 1945,

TABLE III

CLINICAL FINDINGS

Case	Trendelenburg Test	Presence of Limp	Amount of Shortening (*Centimeters*)	Use of Brace, Crutches, or Cane	X-ray Evidence of Degenerative Arthritis	Condition of Head
1	Negative	None	1	None	None	Live
2	Negative	None	2	None	Plus-minus	Dead
3	Negative	None	1	None	None	Live
4	Negative	Slight	1.5	Cane	None	Dead
5	Negative	None	1.4	Walker *	None	Live
6	Negative	None	3	None	None	Dead
7	Positive	Marked	2	Cane	Plus	Dead
8	Negative	None	2	None	None	Live
9	Negative	Slight	2	None	None	Dead
10	Negative	None	2	None	None	Live
11	Negative	None	1.5	None	None	Dead

* Multiple sclerosis was present in this case.

microscopic sections taken from a twenty-year-old hyaline-cartilage graft (Fig. 13). which had been employed by John Staige Davis in the repair of a saddle nose. Slight buckling had necessitated partial excision; hence a specimen of the twenty-year-old transplanted cartilage was obtained. It proved to be normal hyaline cartilage. This work and that of Fisher, Carter, Loeb and Siebert, Logan, Hills, O'Connor, Falconer, and others point rather conclusively to the value of autografts of hyaline cartilage.

Sherman and Phemister, in 1947, published a paper on the pathology of ununited fractures of the neck of the femur and concluded that, if the blood supply of the head is cut off, the head dies and the articular cartilage becomes necrotic. The cartilage remains unaltered until the blood supply reaches it, and is then replaced by either an imperfect type of fibrocartilage or by bone. This excellent piece of work casts considerable doubt upon the value of the cartilaginous-cup arthroplasty. However, the historical data as well as the clinical and roentgenographic findings reported in this article, particularly the findings in the nine-year-old cartilaginous cup in Case 1 (A. M.), point to the contrary. In the eleven cases reported in this series, the head was completely removed from the acetabulum in each case. In two instances there was slight bleeding; in the other nine, no bleeding occurred. Unfortunately, no bone sections or cartilage sections were studied at the time of the cup arthroplasty, so that there is no microscopic evidence as to which head was dead and which was viable. Six cases showed roentgenographic evidence of a dead head; the remainder, viable heads (Table III). The complete removal of the head certainly deprived the cartilage of all blood supply.

It is hoped by the writer that this presentation will stimulate thought on hyaline-cartilage autografts. Their possible application to smaller joints, particularly those of the hand and foot, seems practical. The writer has under observation at this time a number of old congenital club feet upon which reconstructions have been performed through the usual approach of a triple arthrodesis. The cartilaginous surfaces were reapplied after the desired bony reconstruction was done. Movement in these joints, instead of fixation, has been obtained. The results to date in several cases (after one year of follow-up) have been striking. This material will be analyzed and reported after adequate time for proper analysis has elapsed.

Homografts have been utilized by the plastic surgeons, and cartilage banks have been established for a long time. Perhaps cartilage banks will be a part of the orthopaedic surgeon's armamentarium in the near future.

CONCLUSIONS

The cartilaginous-cup arthroplasty has been proposed as another method for handlin ununited fractures of the neck of the femur, particularly those in Classes II and II The method is admittedly a modification of the Brackett procedure and is similar ana tomically to the methods described by Wagner; Venable, Stuck, and Beach; and others. Its originality, if there be any, is based primarily upon the utilization of the hyaline cartilage of the head of the femur as an autograft transplant. The results in nine cases are considered excellent, and two are poor.

NOTE: The writer wishes to thank J. T. Ealy, M.D., and John Ashby, M.D., Residents in Orthopaedic Surgery at Temple University Medical School; Luke W. Jordan, M.D., Associate in Orthopaedic Surgery and E. E. Aegerter, M.D., Professor of Pathology at Temple University Medical School, for their valuable assistance in the preparation of this paper.

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DISCUSSION

DR. JOSEPH A. FREIBERG, CINCINNATI, OHIO: I was fortunate in seeing Dr. Moore's first case, a nine-year result, last fall. Those of us who saw this woman were really amazed at the excellent restoration of function. Because of my impression of this case, and on the basis of what Dr. Moore told us, I decided to carry out the procedure in the next case that presented itself. I have done the operation in two cases. Unfortunately, neither one was an ideal patient for a reconstruction operation, but I am satisfied with the results. Before I show lantern slides of these patients, I want to mention one or two facts.

First, Dr. Moore did not state that, when you have the head in your hand and are reaming it out with the burr, the head has a tendency to get away from you. This happened to me on one occasion, and I could not be persuaded to put it back. I finished this operation as a Whitman reconstruction. This hip is progressing at about the same rate as though an arthroplasty had been performed.

The second criticism is the difficulty of putting the cartilaginous cup back on the neck at the original angle. If this is not done, the hip-joint relations are permanently disturbed. The cartilage cup should be replaced as accurately as possible. In two of Dr. Moore's cases, one four months and the other five months after operation, there is limitation of extension. Neither one of these was an ideal case. In the moving picture which Dr. Moore has showed, there appeared also to be some limitation in extension, as in the last case.

I wish to show the slides of my cases: This man, aged fifty-two, had had a left hemiplegia in 1944 and fracture of the femur, treated elsewhere with traction, which resulted in non-union. He came in because the non-union. He had a contracture of the knee of about 15 degrees, as well as some flexion contracture of the hip. From the postoperative roentgenogram, it appears that the head is not so well placed on the nec as it might be. This is a point which Dr. Moore brought out. In the lateral view the head has not slipped The amazing thing is the firmness with which the cup was fitted at the time of operation. We did not hav any difficulty in keeping it from being displaced. This man is shown four months after his operation. He i exceptionally well pleased with the result. He walks on crutches, with limited weight-bearing. He has nov 70 degrees of motion, but he still has some flexion contracture and limitation of extension of the hip to 1 degrees. Clinically, he appears to have an excellent result.

This second man, aged fifty-five, had a fracture of the neck of the femur. He was treated elsewhere, and non-union resulted. The head appeared to be viable. He had a full-thickness tibial graft and a Smith-Petersen nail reconstruction, done in January 1947. He complained of pain. It was not an ideal case for reconstruction. This roentgenogram was made in June 1947, five months after operation. There is one screw in the shaft. The patient has slight limitation of motion. He is putting some weight on the leg, with crutches He now has 60 degrees of flexion in the hip.

I do not believe that the end results in my cases are as good as those in Dr. Moore's cases, but I am satisfied with them so far.

Dr. Paul C. Colonna, Philadelphia, Pennsylvania: Although I have not had any personal experience with this operation, the results shown here are very impressive in the treatment of selected cases of non-union of the neck of the femur. Technical difficulties may occur in reaming out some of these femoral heads, however.

The technique described by Dr. Moore presupposes that one is dealing with viable articular cartilage. Unfortunately, many of these loose heads present marked evidence of damage which has been produced by misplaced pins and nails,—not infrequently cartilaginous degeneration or areas of fibrillation. In addition, certain cases present ischaemic or avascular necrosis of the entire loose head. In these instances, it is difficult to say whether any portion of the head fragment should be used. In those cases in which the head fragments cannot be salvaged, other types of reconstruction operation are desirable.

Certain cases present narrowing of the joint space, indicating cartilage destruction. At times there is arthritis, and these cases are best treated by arthrodesis.

However, this still leaves a number of old ununited fractures of the hip with a viable head and a normal joint space, for which this operation may be ideally suited.

This operation, which might be called a modification of the Brackett operation, could have a far wider application than the author has described,—for instance, the utilization of the articular cartilage to produce an arthroplasty. If it is possible to restore function by using the joint cartilage over the head of the femur, why cannot joint cartilage be used in other joints? Will it be possible to restore function by preserving the articular cartilage of many joints by the use of cartilage banks, as we are doing today with bone banks, utilizing both heterogeneous and autogenous grafts?

I would like to compliment Dr. Moore on finding another method for treating non-union and, more important, for using the principle he has illustrated in the restoration of joint function. This may be the answer to many of our problems in the reconstruction surgery of joints.

Dr. I. William Nachlas, Baltimore, Maryland: It has been the concept of arthroplasty that one good articular surface is all that you need to get good motion. Are the beautiful end results that we saw in these illustrations the result of saving that cartilaginous cup, or are they the results of the superb technique that Dr. Moore has used?

Dr. M. N. Smith-Petersen, Boston, Massachusetts: I have had no experience with this procedure I think that the principle of reconstruction may be a little different from what Dr. Moore thinks it is. He showed some beautiful slides of a "new head". I question whether the "cartilaginous cup" actually survives as an articular surface. In my opinion, the cartilaginous cup surrounded by a blood clot is exposed to the acetabulum, which acts as a mold. The blood clot undergoes metaplasia and is gradually transformed into hyaline cartilage. This, then, is new hyaline cartilage, and the photomicrographs will probably show the cartilage cells running parallel to the joint surface rather than perpendicular, as they do in normal hyaline cartilage.

I believe, then, that the principle is really that of mold arthroplasty.

Dr. John R. Moore (closing): The use of homografts of hyaline cartilage is not new. They have been employed by the plastic surgeons and the rhinolaryngologists for many years. The possible application of homografts of hyaline cartilage to orthopaedic surgery is primarily the purpose of this presentation. Cartilage banks may be part of the armamentarium of the orthopaedic surgeon in the future.

MANAGEMENT OF CHRONIC OSTEOMYELITIS SECONDARY TO COMPOUND FRACTURES

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In World War II early, adequate surgical care, rapid evacuation, and the use of chemotherapeutic and antibiotic agents made possible early closure of compound wounds by delayed sutures. The number of cases of osteomyelitis developing from compound fractures was, therefore, creditably small. Delayed primary or early secondary closure was not attempted in all cases. Many wounds were healed or almost healed by the time the men reached a permanent installation. In other cases, closure was not attempted, because of the severity of the infection or the multiplicity and extent of the wounds. Furthermore, delayed closure of compound fractures was not always successful. Whatever the cause of failure, a considerable number of patients with chronic osteomyelitis were returned to the Zone of Interior. These presented a real problem in reconstruction, varying from the patient with a small draining sinus and a small bone cavity to those with extensive soft-tissue destruction and great loss of bone substance.

It seemed imperative, therefore, that a method of therapy be used that would lead to rapid healing of the infection and would include provision for bone replacement and final wound closure.

Two methods of obtaining early healing of the osteomyelitis had been established:

1. Healing of the infection by the application of skin grafts, following débridement and saucerization, as advocated by Lord (1902), Reid (1922), and Armstrong and Jarman (1936).

2. Débridement and saucerization with soft-tissue obliteration of the dead space and primary wound suture, proposed by Dickson, Diveley, and Kiene in 1941 and by Key in 1944.

Satisfactory results have been obtained with both methods.

Kelly, Rosati, and Murray, using an improved technique and aided by chemotherapy, advocated healing of the osteomyelitis, after débridement and saucerization, by a split-thickness skin graft.

The principles set down by Kelly and his associates, with some alteration in technique, were instigated at the Gardiner General Hospital by Lieutenant Colonel Frank West and Captain Charles Stebbins. This method was successful in healing practically all of the cases of chronic osteomyelitis, although in a few cases more than one operation was required. Three of the patients reported here required more than one operation before complete healing occurred (Table I).

The problems presented, therefore, were:

1. When and in what cases of chronic osteomyelitis could this method be used?
2. How much tissue should be removed at the time of débridement and saucerization?
3. How soon after débridement and saucerization should a skin graft be applied?
4. What should be done after healing of the infection?
5. What is the method of management of these cases?

Débridement and saucerization, followed by split-thickness skin grafts, may be used in any case of chronic osteomyelitis, when the acute cellulitis has subsided and the general condition of the patient is satisfactory.

At the time of débridement, all dense scar should be removed so that healthy wound edges remain. At times it is impossible to take out all the scar surrounding the infected

TABLE I

SKIN-GRAFTING WITH 100 PER CENT. TAKE *

Time	No. of Cases
7 to 10 days	9
14 days	5
21 days	6
28 days	11
29 to 59 days	8
More than 60 days (failures)	3
Total	42

* In three cases new grafts were applied, with successful results; in two cases pedicle grafts were used.

area, but failure to do so may cause difficulty in the final closure of the wound. The scar is prone to become ulcerated at the time of the skin-graft closure. All foreign material must be removed. This includes shell fragments, pieces of clothing, and metal used for internal fixation of the fracture.

All dead and infected bone must be removed, and as much dense sclerotic bone adjacent to the infected bone should be removed as possible, care being taken not to destroy useful bone, down to healthy appearing bleeding bone. Where large granulation areas exist about the fracture, these may be decreased by a skin graft to improve the condition of the patient, but it is useless to apply a skin graft or flap to a sinus or ulcer with infected bone beneath. This bone must be cut away to prepare an adequate bed for the graft or other type of wound closure.

Therefore, at the time of débridement and saucerization, one should not be concerned

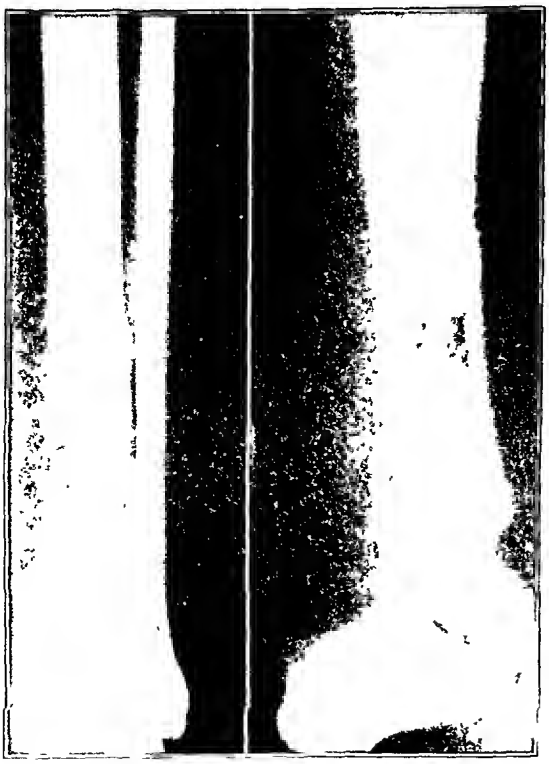

FIG. 1-A

FIG. 1-B

Fig. 1-A: Before débridement and saucerization.
Fig. 1-B: After débridement and saucerization.

FIG. 1-C

FIG. 1-D

After healing with skin graft.

FIG. 1-E

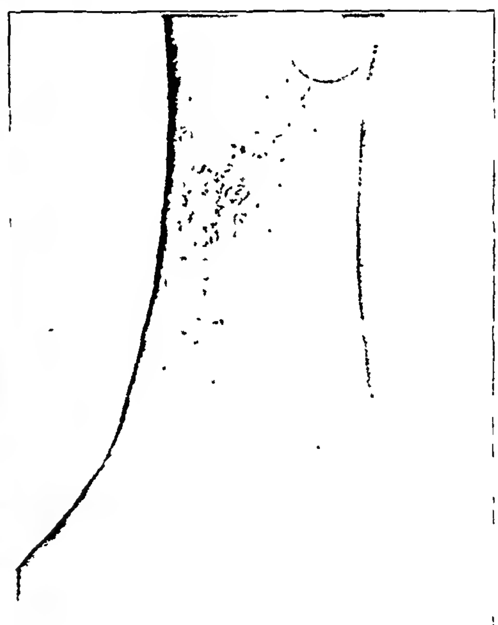

FIG. 1-F

Fig. 1-E: Final closure of wound after healing of third stage.
Fig. 1-F: Obliteration of bone cavity with block of iliac bone.

with the problem of closure of the wound, but should be aggressive enough to proceed to healthy tissue, both skin and bone. The saucerization must be good so that, if possible, no pockets or ledges are left, as their presence increases the difficulty of application of skin grafts. The skin graft should be fashioned to fit into each pocket and crevice of the bone (Figs. 1-A to 1-F, inclusive).

At the same time one should be cautious not to remove bone unnecessarily, so that

a dehiscence or a pathological fracture results. Reinforcing a weak bone, as brought out recently by Carpenter, Rosenfeld, and Mech, is not such a formidable procedure as replacement of large bone defects. However, if it appears that complete interruption of the bone is necessary to remove all dead tissue, then this should be done; otherwise failure of closure will result. We see, then, that not to do enough leads to poor results, and to go too far produces prolonged disability and major surgical repair. Following débridement and saucerization in the cases of osteomyelitis in which the wound is packed open, an interval of five to seven days should elapse before application of a split-thickness skin graft. The authors prefer to wait seven days. The packing may be removed on the sixth day, and a wet dressing of normal saline may be applied before the graft.

With complete healing of the skin graft and closure of the osteomyelitic focus, there is a steady decrease in the size of the defect. Surrounding skin is easily loosened by massage and active exercises. Also, there is active proliferation of connective tissue beneath the grafts, so that the pocket becomes shallower. The filling out of the pocket has been described by Lord, Reid, and others. They gave this as a reason for leaving the skin graft as a permanent covering. The authors found that, at the time of removal of the graft, there was a distance of one to one and one-half inches between the skin and the bone. It is our feeling that contracture of this scar tissue, with resultant circulatory embarrassment, is the most important cause of the ulceration and recurrence of infection.

After healing of the infection, some previously ununited fractures united. It is important that they be properly splinted during this stage, as union occurred in one of our cases quite rapidly after closure of the wound, while splinting was inadequate, so that angulation occurred and an osteotomy was necessary.

With sufficient solid bone and a small skin pocket, no further surgery is needed. However, the lesion must be so located as to be free from trauma. The majority of patients treated by débridement, saucerization and split-skin grafts alone were left with a skin pocket, which tended to collect dirt and was prone to break down. They also had deficient remaining bone. We feel that the bone pockets should be filled, both for stability and because this scar-filled pocket is subject to vascular change and necrosis.

The average duration of the osteomyelitis was nine and one-half months; the shortest duration was two and one-half months, and the longest twenty-five months. The average patient had already had four operations; one patient had had eleven operations and the wounds had all healed by the procedures outlined.

Considerable attention should be paid to the general condition of the patient. Good results depended to some extent upon how well the patient's condition could be improved with diet, vitamins, and blood before the operation. All were cases of long standing, and the patients had had several surgical procedures and had traveled long distances. The majority had been bedfast from the time of injury. Sulfonamides were occasionally used, when the patients had sensitivity to penicillin; otherwise, penicillin alone was used. Starting forty-eight hours before operation, 20,000 units was administered every three hours until fourteen days after operation.

All sequestra were carefully removed. Sclerotic eburnated bone was also removed down to healthy bleeding bone, and care was given to fashioning a saucerization so that no unnecessary pockets or overhanging ledges were left. The tourniquet was then released and active bleeding was controlled. Oozing was given a little time to decrease, and the cavity was packed with fine mesh gauze, soaked in glycerine. After trying a large variety of materials, Captain Stebbins found that glycerine was preferable in that it did not macerate the tissue and it allowed separation of the pack without damage to the granulation tissue. It could be removed and a skin graft could be applied without a preliminary wet dressing. However, most wounds were dressed prior to skin-grafting, and wet dressings were applied. After packing of the wound, a plaster cast was applied.

From the fifth to the seventh day the wounds were inspected. If found to be clean,

TABLE II

SITE OF INFECTED FRACTURES

Bone Involved	No. of Cases	Total
Femur		
Upper third	1	
Lower third	6	
Middle third	6	13
Tibia		
Upper third	7	
Lower third	3	
Middle third	10	20
Humerus		
Upper third	3	3
Ilium and sacrum		1
Foot		5
Total cases		42

a split-thickness skin graft was sutured to the wound edge, and was packed carefully into the bone defect with cotton soaked in glycerine. The packing was done meticulously until above the level of the skin. This was then covered with fine rubber tissue to prevent drying and hardening, and a pressure dressing was applied. Where stability was required, a cast was also applied. Seven days after operation the dressing was changed, the cotton was removed, and all necrotic portions of the graft were trimmed away. The results of skin grafts, in the forty-two cases in which the end results are reported, are shown in Table I.

In no case was a skin graft applied at the time of saucerization, as in about seven days a thin granulation tissue develops over the raw bone and facilitates the ability of the graft to take.

The final or third stage consists in removal of the skin graft, obliteration of the bone defect with a bone graft, and closure of the wound. Of the cases treated thus, forty-two were followed for at least six months; these are reported. Table II shows the location of the lesion. Cultures were taken routinely but were of little clinical value, as the gross appearance of the wound determined whether or not it could be closed.

After the wound had healed, some fractures united. This is desirable and worth waiting for. Oedema subsided with wound healing, and the size of the defect decreased. Gentle massage loosened the remaining healthy skin, so that final closure could be done many times without shifting skin flaps. We felt that the danger of a flare-up of infection after the bone graft should decrease with time. The general condition of the patient improved. He gained weight, became ambulatory, and began to overcome atrophy, so that better results from the bone graft were assured.

After several months, however, either because of trauma of use or constriction of the scar, the grafts were prone to become ulcerated, which delayed the final operation. Therefore, the authors feel that twelve weeks is about the optimum interval before the final operation. In this series, the average interval was fourteen weeks, the longest being thirty-two weeks and the shortest five and one-half weeks.

Prior to the final stage, careful attention must again be paid to the preoperative condition of the patient. Blood transfusions were found to be more important than penicillin for the success of the operation. By the fifth day after operation, in spite of multiple transfusions at the time of surgery and afterward, the total serum protein was low, particularly the globulin fraction. This caused considerable concern as to the patient's ability

to combat his infection. Penicillin was stopped in several cases at the end of the seven days, when sutures were removed; the wound seemed healed at that time, but drainage developed a few days later. Therefore, the penicillin was continued for fourteen days.

The final or third stage involves the usual preoperative preparation. With the use of a pneumatic tourniquet, the skin graft was dissected from the skin margin. Then it was easily shelled out of the bone cavity in one piece. The bone bed was freshened with a chisel, the tourniquet was removed, and the wound was packed, while a bone graft was being obtained. In this way the bleeding had subsided by the time of application of the graft, and the hematoma was decreased. Cancellous-bone chips were used in all bone cavities. Iliac bone from which a major portion of the cortex had been removed seemed best, but some cavities were so large as to require all available bone to fill them. Where the

Fig. 2-A

Fig. 2-B

Fig. 2-A: Appearance of wound after débridement and saucerization.
Fig. 2-B: Following healing of osteomyelitis with split-thickness skin graft.

Fig. 2-C Fig. 2-D Fig. 2-E

Figs. 2-C and 2-D: Appearance of bone cavity after healing with split-thickness skin graft (Fig. 2-C) and after packing with bone chips (Fig. 2-D).
Fig. 2-E: Final appearance after obliteration of bone cavity with cancellous-bone chips.

Fig. 2-F
Wound and bone graft after final closure.

efect in the bone was shallow, a block f iliac bone was used. In a few cases vith large bone loss, repair was done vith sliding and onlay cortical grafts, ixed with metal screws. In cases with one cavities, the bed was merely reshened to bleeding bone. No attempt was made to drill about the area or to open the medullary canal.

Where non-union existed, the medullary canal was opened in all cases. The bone ends were freshened and, where extensive sclerosis was present, multiple drilling was done. The wounds were then closed in layers, wherever possible without drainage (Figs. 2-A to 2-F, inclusive).

Several patients required shifting of skin flaps for closure, and wounds on the feet were closed with tubed pedicle grafts which had been put in place prior to bone-grafting. After closure, casts were applied in all cases requiring additional stability. Pressure dressings and Thomas splints were used in those with sufficient bone strength.

In twenty-six or 61.9 per cent. of the cases, the wounds healed by first intention following the use of bone grafts. Three or 7.1 per cent. of the cases had slight drainage from a portion of the wound, but without cellulitis or deep infection; these wounds healed within four weeks and remained healed. In four or 9.5 per cent. of the cases, postoperative drainage developed; these wounds healed within eight weeks and remained healed. There was no evidence of deep infection or of sequestration; the bone united.

In four or 9.5 per cent. of these cases, superficial drainage developed and continued for as long as sixteen weeks before final healing occurred. No sequestration occurred. The wounds remained healed as long as we were able to follow the patients (about six months). The exact healing time is not known; the wounds were found to be healed after removal of the casts, which were changed about every four weeks.

In five or 11.9 per cent. of the cases, healing failed to occur. In one patient revision of the wound edges was done, followed by complete healing. One wound healed after a split-thickness graft had been applied to a superficial ulcer on the margin of the wound. The osteomyelitis recurred in three cases and the entire process had to be started again. The end results in these three cases were not known, because this work was stopped, owing to the closure of the Hospital. A number almost equal to that reported was not included, because the patients were still in the process of treatment at the time the Hospital was closed.

We see, then, that in twenty-six cases, or 61.9 per cent., the wounds healed by first intention and remained healed. Their bone grafts also appeared to be healed when last seen. Eleven or 26.2 per cent. had postoperative drainage from hematomata or necrosis of the wound edges, but healing occurred without further surgery, sequestration, or bone grafts. Healing occurred in two cases after revision of the wound edges. Three cases, or 7.1 per cent., were failures.

SUMMARY

The authors feel that the management of osteomyelitis secondary to infected compound fractures should consist in débridement and saucerization, with closure of the wound by primary suture, if it can be done without excessive tension. Otherwise, the method of delayed closure by split-thickness skin grafts should be used.

After healing of the infection, union will occur in many cases of previous non-union.

Many patients need no further surgery after wound healing because of adequate remaining bone, and because the bone and skin pockets are small.

With non-union, large bone defects, or large bone and skin pockets, and in those cases in which reinforcement is required for stability, three months should elapse after complete healing of the wound before bone-grafting is done.

The use of cancellous bone, from which as much cortex as possible has been removed is recommended. If the defect is large, it may be difficult to obtain sufficient bone without the use of cortical chips. The authors have had no experience with bone grafts at the time of débridement and saucerization, but this seems to be the next step in evaluating the management of chronic osteomyelitis.

Careful preoperative and postoperative preparation with antibiotics and blood transfusions is essential.

As postoperative drainage appeared to result from hematoma, which was prone to become infected, it is suggested that delayed primary closure of the wounds would give a higher percentage of complete early healing.

The authors see no reason why chronic osteomyelitis of hematogenous origin could not be managed in a similar way.

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SURGICAL PROCEDURE FOR LYMPHOEDEMA OF THE EXTREMITIES

A Follow-up Report*

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Many cases of lymphoedema, irrespective of the cause of lymph stasis, progress to the point of disability as a result of the development of recurrent cellulitis and lymphangiitis, or the enlargement of the extremity to elephantine proportions, or a combination of both. The more disabling complication, recurrent cellulitis and lymphangiitis, frequently produces severe general reactions, sometimes of an alarming nature.

Although it is not the purpose of this paper to discuss the etiology of lymphoedema, it seems appropriate to offer the general impression of many authors concerning the cause of recurrent cellulitis and lymphangiitis.

Sabouraud and Unna first called attention to the possible etiological significance of the Streptococcus in cases of progressive lymphoedema associated with erysipelas-like attacks. Unna further explained the periodic attacks on the basis of incomplete healing of the original lesion, which results in a vascular disturbance and an incomplete destruction of the streptococcus. Reichert, in 1929, stated, "Simple lymph edemas are the result of stasis. Add the factor of infection and we have an entirely different picture, that of elephantiasis. Chronic infection, usually caused by a streptococcus, after a time, readily leads to a progressive hypertrophy of the hypodermal and dermal connective tissues. . . . Simple mechanical blockage of the lymphatics causes regional lymph edema, but the characterictic fibromatosis, and the histologic changes peculiar to elephantoid states, cannot be produced without pyogenic infection."

Halsted, in 1921, demonstrated that radical excision of the axillary glands or axillary vein, or both, will not, in itself, produce this condition. To produce elephantiasis of the upper extremity, there must also be a secondary infection. To support this contention, there have been reports by such authors as Stevens, Homans, Drinker, Field, and their co-workers[4,5,6,12]. In some instances, these reports have been supported by laboratory experiments.

In 1940, Ochsner, Longacre, and Murray, in a very excellent and comprehensive review of the literature on the subject of lymphoedema, concluded that, "Elephantiasis is the end result of recurrent erysipeloid lymphangiitis, produced by pyogenic infections, usually the streptococcus. Lymphedema is a predisposing factor for the pyogenic infection which causes the inflammatory reaction which is responsible for the ultimate fibromatosis."

The pathological changes which accompany the late stages of lymphoedema, in the cases comprising this report, have consisted of replacement of the adipose tissue by enlarged lymph spaces and fibrosis of the connective tissue. In two of the patients, the skin and subcutis were thickened, and inflammatory changes were noted, together with an inflammatory process; one of the patients presented gangrenous areas in the skin. In those patients in whom a biopsy of the muscle was made, no pathological changes were noted.

Operative procedures for the treatment of disabling lymphoedema were initiated by Lisfranc early in the nineteenth century by a scarification procedure, according to Keysser. Carnochan in 1851 ligated first the femoral and then the external iliac arteries; many amputations resulted. Handley, Lexer, and Lanz based their methods of treatment on attempts to establish lymphatic drainage. These procedures ended in failure.

* Read at the Annual Meeting of The American Orthopaedic Association, Hot Springs, Virginia, June 27, 1947.

In 1912, Kondoléon, with the same thought in mind, attempted to establish communication between the superficial and the deep lymphatics by the excision of strips of deep fascia, and by placing subcutaneous tissue in contact with the muscle. Matas was the first surgeon to perform such a procedure in this country. The Kondoléon treatment was disappointing in most instances and led to modification by Sistrunk, Auchincloss, Ghormley and Overton, and others. These modifications of the Kondoléon operation were based on a more extensive removal of skin and subcutaneous tissue, which primarily reduced the size of the limb, but failed in many instances to delete the recurrent cellulitis and lymphangiitis and to maintain the postoperative decrease in the size of the extremity.

Other operative approaches have been described by Gillies and Fraser and by Pratt and Wright. These operations consist in transplanting or turning down pedicle skin grafts in a bridgelike fashion, across the trunk to the lower extremity, in order to establish communication between the lymphatics of the leg and those of the trunk. Homans has devised a procedure in which the subcutaneous tissue is excised, but thin skin flaps, which have a very thin layer of subcutaneous tissue, are retained. After excision of the lymphoedematous tissue, these thin skin flaps are sutured into position. He felt that, since the leg was the chief reservoir of fluid, there was no reason to carry the procedure higher than the knee; and that following his complete operation on the leg, the enlargement of the thigh was reduced.

The procedure which prompted this paper was first described in the Staff Proceedings at the Mayo Clinic on January 24, 1940. The first operation had been performed on a lower extremity in May 1939. In the original report, it was stated that the abnormality seemed to be confined entirely to the subcutaneous tissue, since the underlying structures appeared normal, and that the procedure was based on eradication or excision of the diseased tissue, or, at least, excision of the most offending part of the disease process. This observation, that the diseased tissue is primarily subcutaneous, has been borne out over a period of seven years, with the exception of the two cases in which there were inflammatory and circulatory changes throughout all layers of the skin. The absence of recurrent cellulitis and lymphangiitis following this operative procedure supports the contention that recurrent cellulitis and lymphangiitis are a result of recurrent pyogenic infection or a "flare-up" of it in a previously sensitized tissue.

The surgical procedure to be described should be confined to the area below the knee and possibly below the elbow. In none of the patients on whom this procedure has been performed, has cellulitis been observed to extend above the knee; therefore, it would seem that the disabling recurrence of this disease is not only due to a pyogenic infection, but is limited to the area below the knee and is usually confined to the subcutaneous tissue.

In the series of seven cases covered by this follow-up report, four of the patients had had recurring cellulitis and lymphangiitis over a period of years. In none of these has there been a recurrence of cellulitis in the extremity operated upon. Six of these seven cases may be classified as lymphoedema praecox (Allen's classification), and in four of these recurrent cellulitis and lymphangiitis developed as a late complication ten, seventeen, twenty-three, and thirty-eight years, respectively, after the initial evidence of lymph stasis. In two of these six patients, the operation was performed because of progressive enlargement of the lower extremity. The seventh patient had extensive lymphoedema of the forearm, resulting from a lymphangioma in the arm and axilla.

SURGICAL PROCEDURE

The surgical procedure to be described is, unfortunately, not the complete answer in the treatment of lymphoedema. However, it is felt that it is an advance in the right direction, since it does eliminate the disabling feature of recurrent cellulitis and lymphangiitis and maintains the postoperative decrease in the size of the leg.

In lymphoedema above the knee, recurrent cellulitis has not been observed, and the

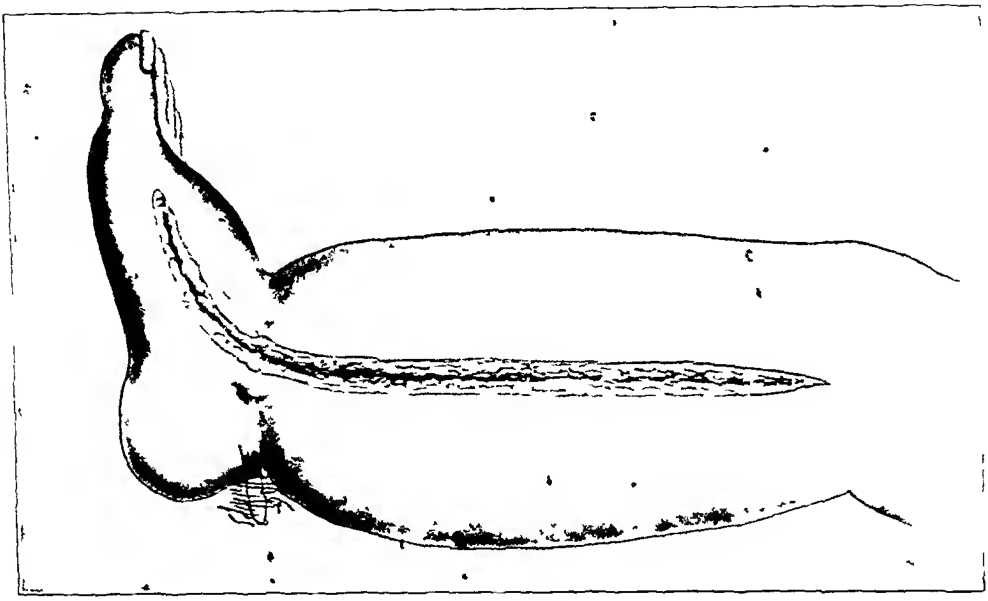

FIG. 1
Schematic drawing, showing the skin incision in the leg

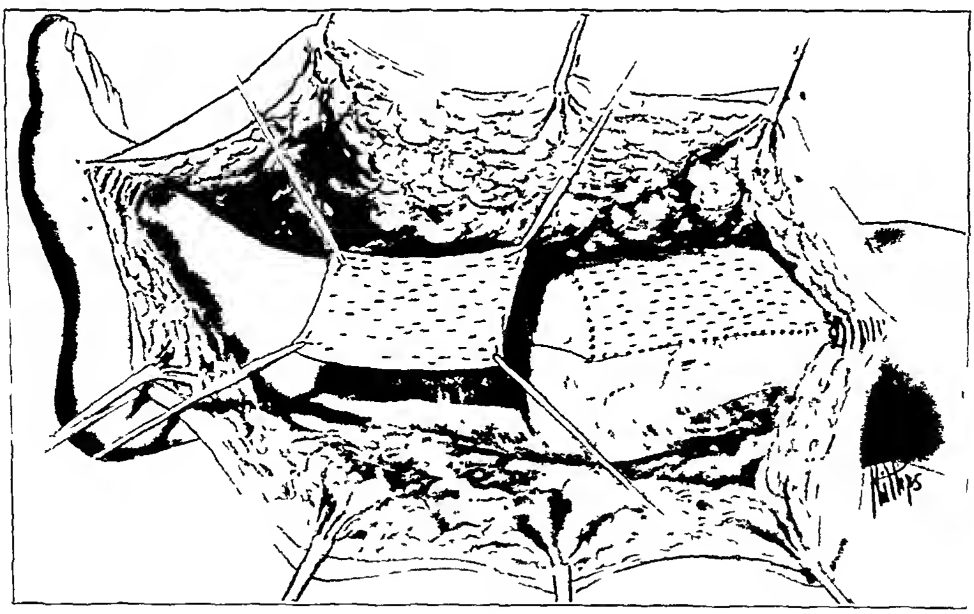

FIG. 2
Schematic drawing, showing subcutaneous dissection of the diseased tissue and the application of split-skin grafts over the muscle sheaths and peritendinous structures.

aim of treatment above the knee is to prevent incapacitating proportions of the thigh. However, it is possible that the enlargement of the thigh may be relieved by some plastic procedure such as the bridging operations of Gillies and Fraser or Pratt and Wright, or by a more simple procedure. We have been able to maintain a satisfactory decrease in the size of the thigh by the use of a thigh support after the operation on the leg

As a preliminary to the operative procedure, the extremity should be elevated for a period of two days and drained of most of the lymphoedematous fluid. If cellulitis is present, a sulfonamide preparation or penicillin (preferably the latter) should be used two

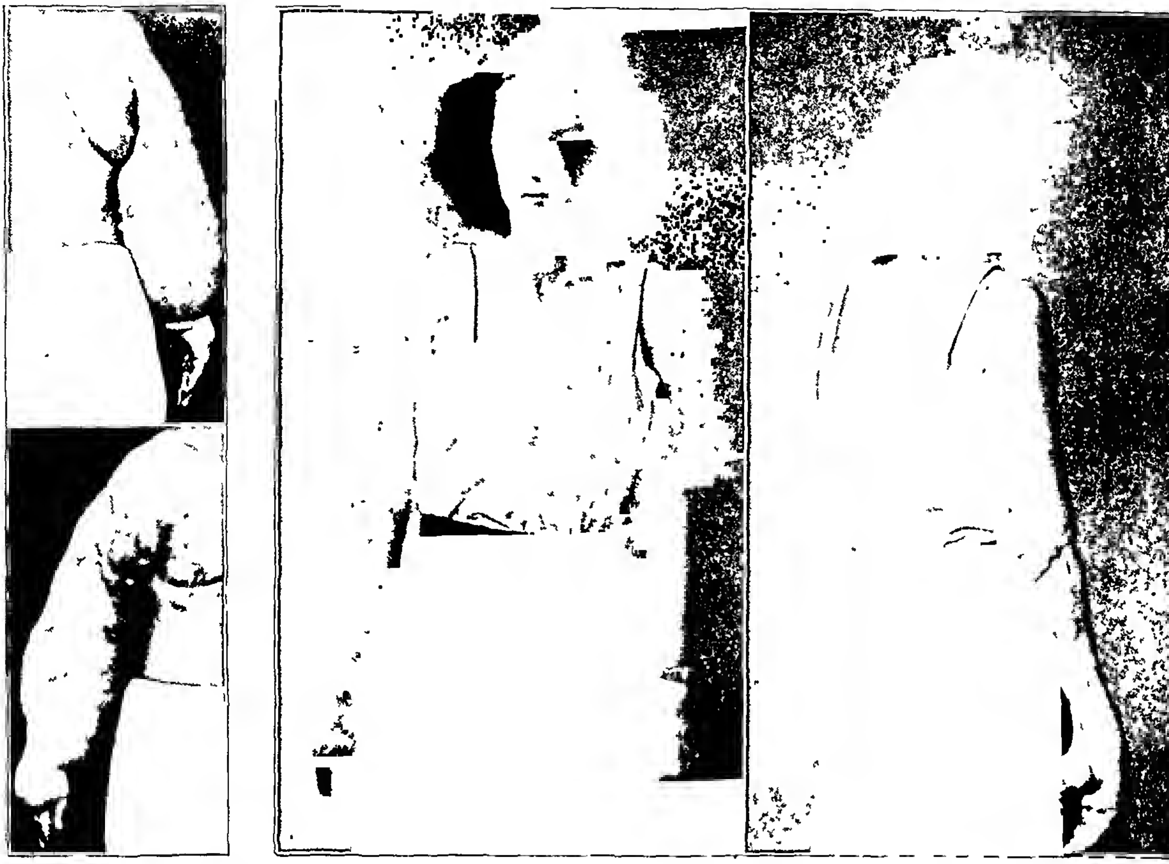

FIG. 3-A FIG. 3-B FIG. 3-C

Fig. 3-A: Extensive lymphoedema of right arm before operations. (Reproduced, by permission of the Mayo Clinic., from *Proc. Staff Meet., Mayo Clin.*, **15**: 50, 1940.)

Figs. 3-B and 3-C: Appearance of right arm of patient seven years after excision of the lymphoedematous tissue and skin-grafting.

to three days preoperatively and continued postoperatively until the second procedure of the operation is completed. If no cellulitis is present, penicillin is not needed preoperatively, but is given postoperatively. At the time of the operation and before the tourniquet is applied, it is well to remove sufficient skin from the thigh for grafting, or to place the tourniquet high enough so that it does not interfere with the removal of these skin grafts from the thigh. Skin grafts may be removed from the leg, if the skin of the leg is uninvolved in the disease process. The operation is divided into two stages; either the medial or the lateral aspect of the leg is chosen for the first stage (Fig. 1).

The technical procedure of the operation is difficult to describe. An incision is made through the skin, subcutaneous tissue, and fascia, extending from the knee to the base of the toes and curving over the malleolus. At the level of the malleolus, dissection is carried posteriorly and distally, so as to approximate the upper margin of a low-quarter shoe. A fine network of areolar tissue or perimuscular and peritendinous tissue is left over the muscles and tendons, which are the recipient areas for the grafts. A thin layer of subcutaneous tissue is left over the periosteum. The grafts are placed beneath the elevated subcutaneous tissue and fascia and are sutured into position. The subcutaneous lymphoedematous tissue is then closed over the skin grafts. It is well to place multiple puncture holes in the grafts, since the recipient area is avascular, and it is thought that some nourishment to the graft may be furnished by the overlying subcutaneous tissue through the puncture holes (Fig 2). No drains are used; a firm compression dressing is applied. On the seventh to ninth postoperative day, the overlying subcutaneous tissue is excised, and the subcutaneous tissue adjoining the margins of the graft is removed by undermining; thus a somewhat flat closure of the adjacent skin and the margins of the skin graft is permitted. In no instance have these transplanted, buried grafts failed to take in their entirety. The grafts are supported

y elastic bandages, extending to the knee, for a period of ten to twelve weeks postoperatively. It is not thought advisable to proceed with the second stage until four months have intervened.

In the one case of lymphoedema of the upper extremity in which this treatment was employed, the procedure was completed in one stage. An incision was made over the dorsal aspect of the forearm and extended from the elbow to the heads of the metacarpal

Fig. 4-A Fig. 4-B Fig. 4-C

Fig. 4-D Fig. 4-E Fig. 4-F

Figs. 4-A, 4-B, and 4-C: Appearance of extensive lymphoedema of right lower extremity before surgery.

Figs. 4-D and 4-E: Appearance of right lower extremity six years after excision of lymphoedematous tissue and skin-grafting on the medial aspect of the leg, and eighteen months after excision of lymphoedematous tissue and skin-grafting on the lateral aspect of the leg.

Fig. 4-F: Appearance of the posteromedial aspect of the thigh of patient eighteen months after excision of lymphoedematous tissue and skin-grafting.

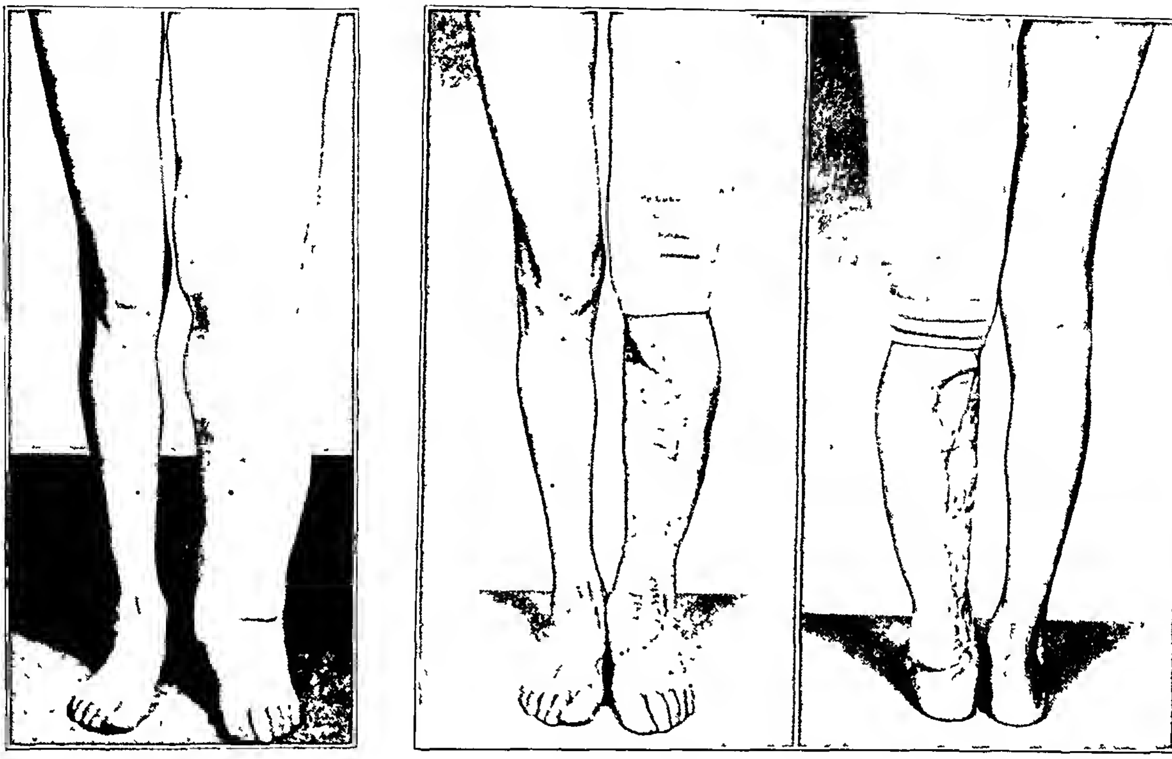

FIG. 5-A FIG. 5-B FIG. 5-C

Fig. 5-A: Appearance of the left lower extremity, showing cellulitis and lymphangiitis in patient who had had a previous, extensive, modified Kondoléon operation.

Figs. 5-B and 5-C: Appearance of left lower extremity after excision of lymphoedematous tissue on inner aspect of the leg. Photograph also shows type of postoperative support used for the thigh.

bones. The lymphoedematous subcutaneous tissue was dissected from the muscles of the forearm in a complete encircling manner. A fine network of fibrous tissue was left over the muscle bellies and tendon sheaths to prevent their adhesion to the skin grafts. Split-skin grafts were then removed from the thigh, transplanted, and sutured into position. The subcutaneous lymphoedematous tissue was then closed over the skin graft without drainage, and was not disturbed for ten days. The lymphoedematous tissue was then excised. The patient's recovery was uneventful, and the result was excellent. In one case, in a lower extremity, the entire procedure was done in one stage, but such extensive surgery is not recommended.

Unfortunately the postoperative appearance, as would be anticipated, is one of scarring; and, in the lower extremity, the skin grafts have shown changes associated with stasis, which have resulted, the author believes, from the avascularity of the recipient site and the dependency of the lower extremity. However, the grafts may be maintained in good condition by the daily use of a softening hand cream. This change has not occurred in the one case in which the operation was performed on the forearm,—probably because of less dependency and the absence of the function of weight-bearing.

RESULTS

Of the seven cases reported in this series, five of the patients have had excision of all of the lymphoedematous tissue below the knee, and one patient has had only the first-stage procedure on the medial aspect of the leg. One patient had lymphoedema of the upper extremity and has had complete excision of the diseased tissue below the elbow, combined with skin-grafting. In this instance of excision and skin-grafting of the upper extremity, the result was excellent.

Of the six patients in whom the lower extremity has been treated, four have had excellent results. In one of the two remaining patients, superficial ulceration in the graft developed; and, from correspondence, this is thought to have been due to changes asso-

ciated with stasis. However, prior to surgery, the involvement of the lymphoedematous extremity was so extensive that the patient was invalided from cellulitis and superficial gangrenous changes in the skin. Since surgery she has been active, and the postoperative decrease in the size of the extremity has been maintained. In spite of her improved condition, she cannot be considered as having obtained a satisfactory result. In the remaining case, a long follow-up was not obtainable. At the end of one year, the skin grafts were in good condition and the elephantine proportions of the extremity had been relieved.

CONCLUSIONS

A surgical procedure, which has been used in a small series of cases, has eliminated recurrent cellulitis and lymphangiitis by excision of the diseased tissue that results from lymph stasis; the postoperative decrease in the size of the extremity has been maintained.

The results in these cases would support the belief that recurrent cellulitis and lymphangiitis, associated with lymphoedema, are produced by a recurrent pyogenic infection.

It is felt that recurrent cellulitis associated with chronic lymphoedema is confined to the tissue below the knee, and is best treated by excision of the disease-bearing area and by skin-grafting.

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DISCUSSION

Dr. Ralph K. Ghormley, Rochester, Minnesota: I believe Dr. Macey deserves full credit for the development of this operation. The treatment of lymphoedema has been by no means satisfactory. My own impression, from what I have seen of this operation and some of the results, is that it is probably the operation of choice where there is extensive skin damage. The young woman who comes to you with early lymphoedema and wants to be cured without any deformity presents a most difficult problem. I believe that with Dr. Macey's operation you can reduce the size of the leg, but you cannot promise a satisfactory cosmetic result in the mild case, seen early. I think the Homans operation offers better results than the others developed up to now. I feel that where you have good skin, the Homans operation should be performed. It is, in my hands, a simpler operation with much less risk than Dr. Macey's.

I want to congratulate Dr. Macey on the conception and development of this procedure.

Dr. Daniel C. Elkin, Emory University, Georgia: Lymphoedema of the extremities is a surgical problem of vital importance, because of the progressive disability which the condition produces. The recurrent episodes of cellulitis and lymphangiitis, with the associated pain in the extremity, malaise, and elevations of temperature, result in great economic loss and give rise to annoying, unpredictable, recurrent illnesses. Many patients are in constant fear of these attacks of illness. A minor abrasion or excoriation of the skin in such an individual will frequently precipitate the recurrence of the infection.

Patients who have an enlargement of the extremity without skin changes are frequently not receptive to the idea of a radical operation, such as that reported by Dr. Macey. In these individuals, a satisfactory result may be obtained through excision of the involved fibrous connective tissue below the knee. In these instances, the subcutaneous tissue is so completely removed that the remaining skin is, in effect, a full-thickness skin graft. In a two-stage operation, the subcutaneous tissue of a patient's leg was completely excised except in the anterior and posterior mid-line. Satisfactory results were obtained.

With the continued enlargement of the extremities which almost invariably occurs, particularly in those instances in which there are recurrent infections, the extremity may attain elephantine proportions. At this stage, the skin usually becomes thickened, vesicle formation is frequent, and the skin becomes rough, corrugated, and horny in appearance. Such an extremity is disabling, not only because it is the result of recurrent infection, but also because the actual enlargement of the extremity interferes mechanically with its function. In many instances it may be so disabling that gainful employment is precluded. Extensive involvement of the skin, ulceration, fissure formation, and serous exudation from recurrent vesicles render such an extremity unsuitable for the operation described above. In such patients, the cosmetic deformity is of no consideration, and the procedure of total removal of the diseased tissue with skin-grafting is desirable.

It is well to stress that this procedure should be performed with utilization of a pneumatic tourniquet, since large quantities of blood will be lost in the dissection of the large masses of subcutaneous tissue. The electrocoagulation current has also been found to be a valuable adjunct in expediting the procedure.

Dr. Macey is to be commended for the excellent results he has obtained in the treatment of this disabling condition.

FRACTURES OF THE LOWER END OF THE HUMERUS IN CHILDREN *

BY D. P. McDONNELL, M.D., AND JOHN C. WILSON, M.D., LOS ANGELES, CALIFORNIA

From the Orthopaedic Service of the Los Angeles Children's Hospital, Los Angeles

Attention was directed to a study of fractures of the elbow because certain of these fractures, although well reduced, result in pain, stiffness, and occasionally some deformity. The belief has been prevalent that residual disabilities do not follow well-reduced fractures of the lower end of the humerus in children, barring soft-tissue damage.

On the orthopaedic service of the Children's Hospital, fractures of the elbow occurring during the past decade or more were studied to evaluate the factors involved. It was found that some general conclusions might be drawn concerning the treatment and possible complications of these fractures.

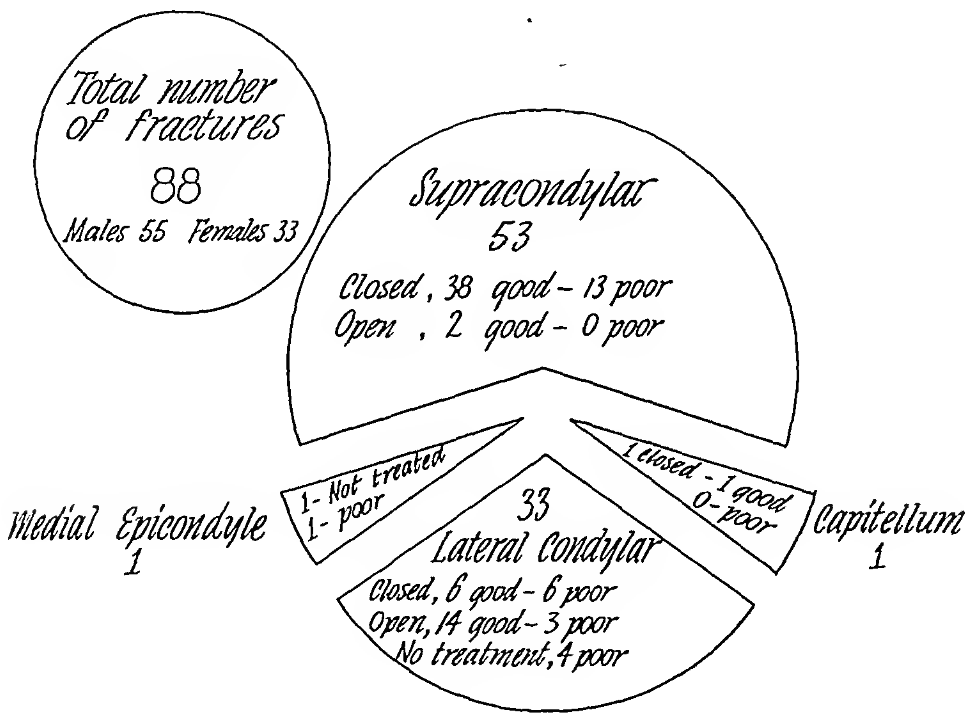

FIG. 1

Follow-up of functional results in group of fractures.

This discussion will be limited to supracondylar fractures and fractures of the lateral condyle, capitellum, and medial epicondyle. Although much has been written about fractures of the elbow involving the epiphyses, these injuries do not receive the attention they deserve. Brewster and Karp have pointed out that in 40 per cent. of fractures of the lateral epicondyle and capitellum, the end results are poor.

The elbow is a ginglymus joint, capable of flexion and extension. It, therefore, presents the following characteristics: (1) convex and concave bony surfaces; (2) muscle masses anterior and posterior to the bones to flex and extend the elbow; (3) a lax capsule anteriorly and posteriorly to allow these movements; and (4) strong collateral ligaments to limit medial and lateral motion.

* Read at the Annual Meeting of The American Orthopaedic Association, Hot Springs, Virginia, June 28, 1947.

A general knowledge of the anatomy, osseous development, and roentgenograph interpretation of the elbow region is essential to evaluate this group of fractures.

The lower end of the humerus is flattened from the anterior to the posterior aspects, is set obliquely, and is lower medially than laterally; thus the "carrying angle" is made. The lower articular end of the humerus is formed by two articular surfaces: laterally, the capitellum is adapted to the head of the radius, and, medially, the trochlea fits the trochlear notch of the ulna. The capitellum is spheroidal and articulates with the disc-shaped radial head. In extension, the distal portion is in contact with the radial head; in flexion, the anterior surface is in contact with it. The posterior aspect of the capitellum does not articulate, and on one side it blends with the lateral epicondyle. The margin of the radial disc articulates with the lateral lip of the bobbin-shaped trochlea, and helps to prevent medial displacement of the radius. The trochlea itself articulates with the ulna.

The epiphyseal line separating the trochlea, capitellum, and lateral condyle from the diaphysis runs transversely just above the lateral condylar cartilage. It is, therefore,

FIG. 2-A

Supracondylar fracture in a child of seven with fracture line extending into the epiphyseal plate and with disturbance of the articular surfaces of the joint.

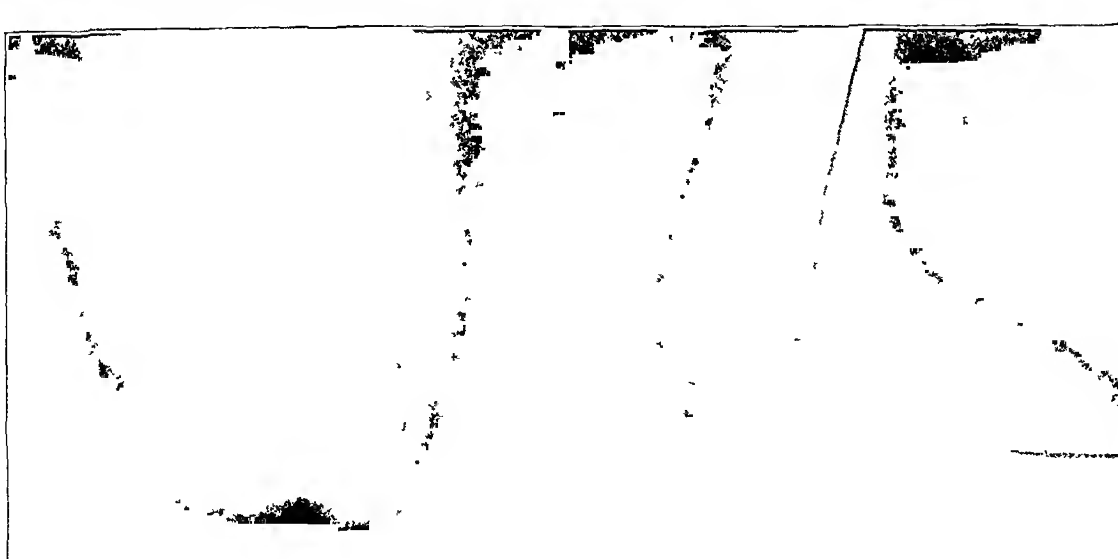

FIG. 2-B

Poor reduction. Fracture is healing with disturbance of articular surfaces.

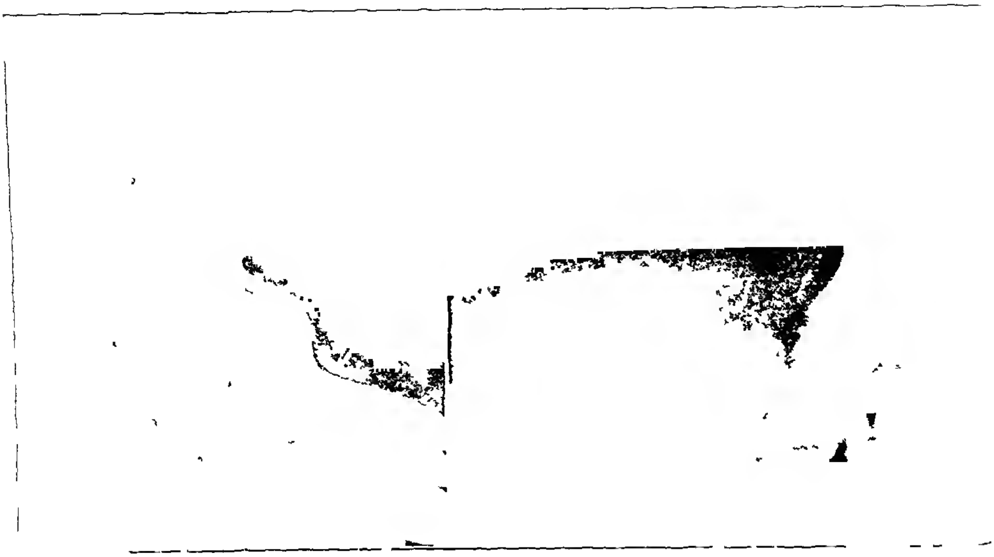

FIG. 2-C

Six years later, lateral views, when compared with those of normal arm (at right), show marked growth disturbances combined with traumatic arthritis. Arm now extends to 135 degrees and flexes to 45 degrees. Deformity is becoming progressively worse.

within the synovial capsule. The medial condyle fuses with a spur of bone that descends from the diaphysis and separates the condyle from the lower epiphysis proper.

Efforts have been made to produce fractures of the medial and lateral condyles and the capitellum experimentally, in order to determine the exact mechanism involved. Kini, working with cadavera, found that in fractures of the lateral condyle located beneath the attachments of the extensor carpi radialis longus and brevis, the condylar fragment was tilted outward and upward with the arm in supination. On pronation, the fragments came together. When the fragments were avulsed by the extensors, the displacement was more exaggerated, but rotation did not take place until the capsule was torn. Chamberlin points out that the normal anatomy of children differs from that of adults in that the cylindrical shaft of the humerus broadens out and thins as it reaches the elbow. The

FIG. 3-A

FIG. 3-B

FIG. 3-A: Supracondylar fracture two years after initial injury, showing posterior displacement of fragment with good general alignment.

FIG. 3-B: Four years later, fractured bone is completely remodeled. Full range of motion in elbow.

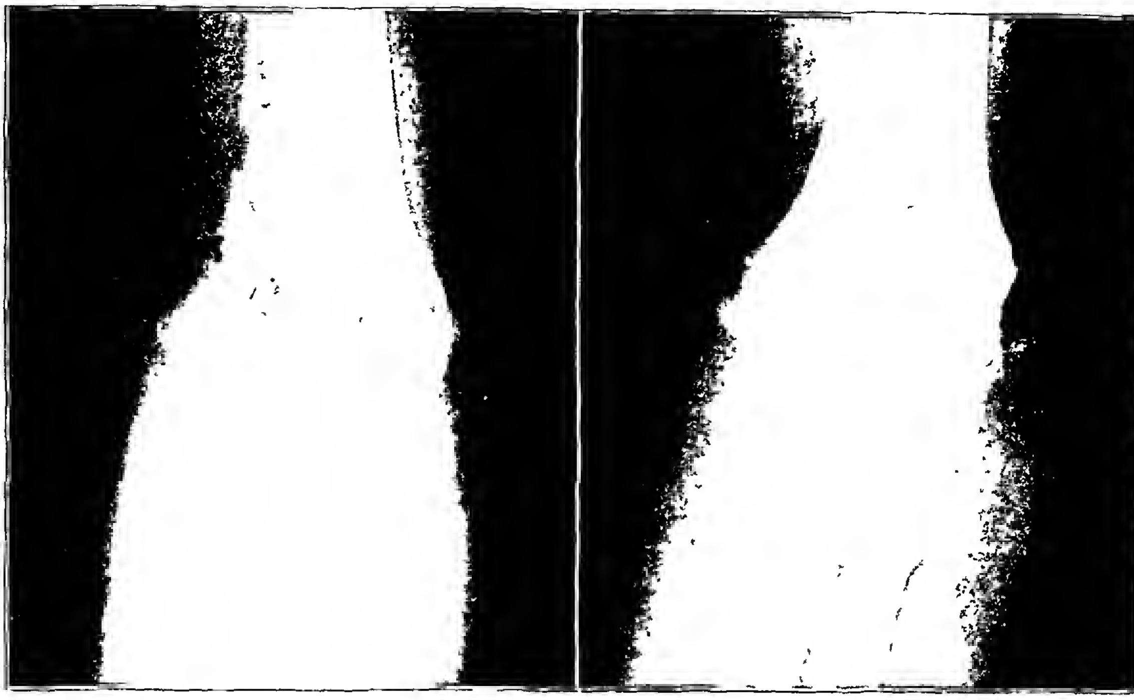

FIG. 4

Supracondylar fracture with medial displacement. Fracture line extends into the epiphyseal plate. Fracture healed with cubitus varus deformity. Full range of motion is present seven years after original injury. (This is an example of good function with a deformity present.)

ventral portion of the lower end has a hollow depression, the coronoid fossa; dorsally, a similar depression is present for the olecranon. In some instances, there is a complete bony defect in the lower shaft of the humerus at the site of these depressions; the cancellous bone makes these regions less resistant to fractures.

A series of 176 fractures of the lower end of the humerus in children was reviewed, and eighty-eight of these were followed long enough to draw some general conclusions with regard to treatment and complications. Of this latter group, fifty-five were in boys and thirty-three were in girls. The ages of the patients ranged from one to twelve years; the average age was seven. There were fifty-three supracondylar fractures, thirty-three lateral condylar fractures, one medial epicondylar fracture, and one epiphyseal separation of the capitellum.

In the present series of supracondylar fractures, end-result studies were obtained on fifty-three patients. Of these, fifty-one were treated by the conventional methods of closed reduction,—manipulation followed by immobilization in acute flexion for from two to six weeks. Traction was employed in those cases in which manipulation was unsuccessful. Of the total number, seventeen patients either had had unsuccessful manipulations or were first seen several weeks after the initial injury. These were treated by traction for periods varying from a few days to three weeks. Two of this number had early circulatory embarrassment, and the fractures were allowed to heal with the arms in optimal position for adequate circulation. One child, whose arm had been in skeletal traction for three weeks in another hospital, was admitted with osteomyelitis of the ulna. The fracture was healing in malposition with considerable callus, and no attempt was made to manipulate the fragments. In one patient a typical Volkmann's contracture and an associated ulnar palsy developed following manipulation of the fragments. The elbow function returned to normal a short time after the fracture. The forearm and hand are slowly regaining function after six years of treatment.

Eight of the supracondylar fractures were followed by cubitus varus and three had cubitus valgus deformities. In one case of severe cubitus valgus, there was an associated late ulnar-nerve palsy.

Of the total number of supracondylar fractures, thirteen, or 25 per cent., had poor

functional results. A static cubitus valgus or cubitus varus deformity with full range of motion was not classified as a bad result. The follow-up period in this group was considered adequate to allow general conclusions, although not strictly representative of a consecutive number of fractures.

Reduction of the supracondylar fractures at the time was considered good in twenty of the total number of patients. General alignment and not anatomical apposition was used as the criterion. A reduction with rotation or forward or backward tilt, which would change the range of articulation, was considered unsatisfactory. Reductions with slight lateral or medial displacements, but without rotation of the fragments, were considered adequate.

Two of the total number of these fractures were treated by open reduction. Both of

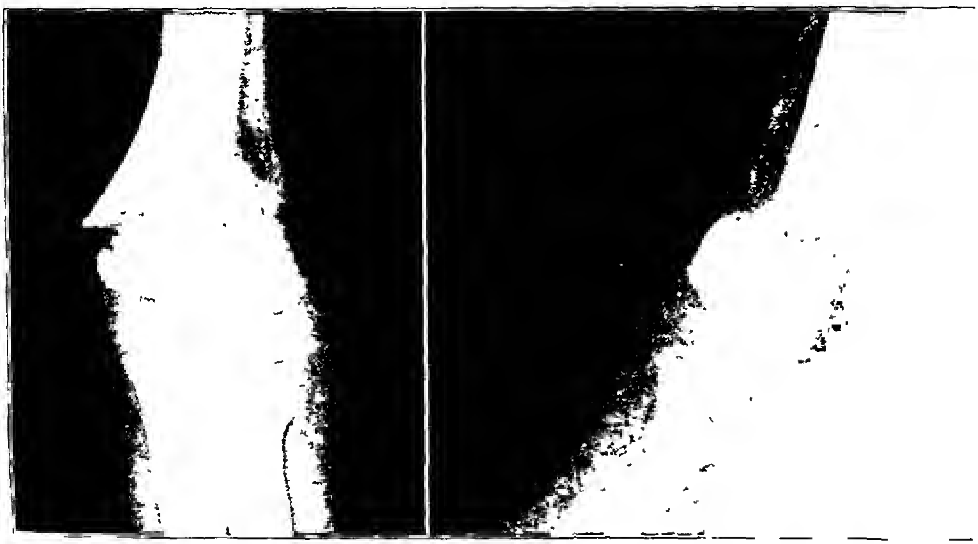

Fig. 5-A

Supracondylar fracture with lateral displacement of fragments. Fracture was treated by traction for three weeks. Good general alignment was preserved.

Fig. 5-B

Seven years later elbow is normal.

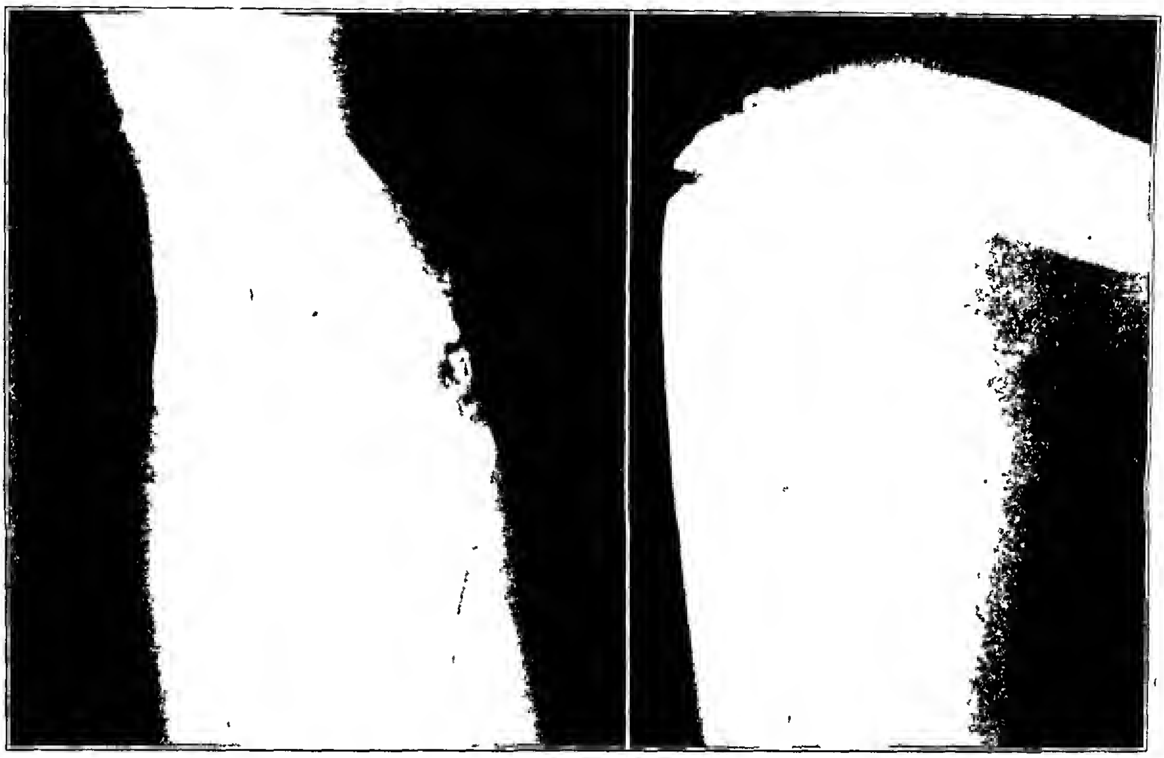

FIG. 6

Supracondylar fracture two years after injury. Three manipulations were required to restore anatomical position. Avascular necrosis of the trochlea is now present.

these were comminuted fractures, in which one or more of the fracture lines were through the lateral condylar region, and the condyle was displaced and rotated. Good results followed nail fixation.

One badly comminuted fracture, in which both condyles were displaced, was treated by traction for three weeks, with good results.

The poor results in this series can be grouped in two classes: (1) those due to poor

FIG. 7

Fracture seven years after original injury, showing irregularity of the joint space due to flattening of the articular surfaces. (Normal elbow at right.)

reductions, and (2) those due to fractures that had extended into the condyles and through the epiphyseal centers.

It is generally considered that, if a supracondylar fracture is reasonably well reduced, there will be little, if any, limitation of movement, and eventually the growing bone will become remodeled to offset any displacement (Figs. 3-A and 3-B). From observations of this group of fractures, this statement is true, with reservations. If the fracture is well above the articular surface and the joint is undisturbed, these fractures will heal with full elbow function. However, if there is forward or backward tilt or rotation of the fragments, the articulating surfaces are deranged, and flexion and extension are limited to a corresponding degree. If the tilt is forward, the olecranon cannot complete its range of motion, and extension will be limited. If the tilt is backward, the range of flexion will be limited. Rotation limits both flexion and extension and adds the strain of antagonistic muscle pull on the articulating surfaces. If the fragments are displaced laterally or medially, a cubitus varus or cubitus valgus deformity may follow, but this is not always disabling. Considerable displacement is allowable, if the general alignment in both planes is satisfactory (Figs. 4, 5-A, and 5-B).

The necessity for accurate anatomical

FIG. 8-A

FIG. 8-B

Fig. 8-A: Lateral condylar fracture with rotation and displacement following inaccurate open reduction and nailing one month after original injury.

Fig. 8-B: Two years after original injury, showing progressive growth disturbance and increasing valgus deformity. The range of motion is limited to 145 degrees of extension and 55 degrees of flexion.

TABLE I

FRACTURES OF THE LATERAL CONDYLES

Complications in Group of Thirty-three Fractures

Complications	No. of Cases
Growth disturbance	8
Non-union	4
Fracture of half of capitellum	2
Ulnar palsy	2
Radial palsy	1
Avascular necrosis of capitellum	1

reduction decreases as the distance from the articular surfaces and the growth centers increases. The remarkable power of growing bone to remodel itself has been apparent in a number of patients with displacement of fragments. If the fracture line, or part of it, extends into the epiphyses, more serious complications supervene, and progressive growth disturbances in the form of early fusion, overgrowth, or avascular necrosis may develop. The fracture may heal and function may return to normal, only to have deformities develop years afterward.

Avascular necrosis of the trochlea developed in four patients within a period of from two to seven years (Fig. 6). In two instances, it was associated with narrowing of the joint space and thinning of the articular cartilage (Fig. 7). In one patient, a capsulotomy was performed seven years after the initial injury, because of marked limitation of extension. This resulted in only a 35-degree increase in the range of extension of the arm. This failure was due to flattening of the trochlea.

Thirty-three lateral condylar fractures were observed in this series. Twelve were treated by manipulation and immobilization, with poor results in 50 per cent., a truly

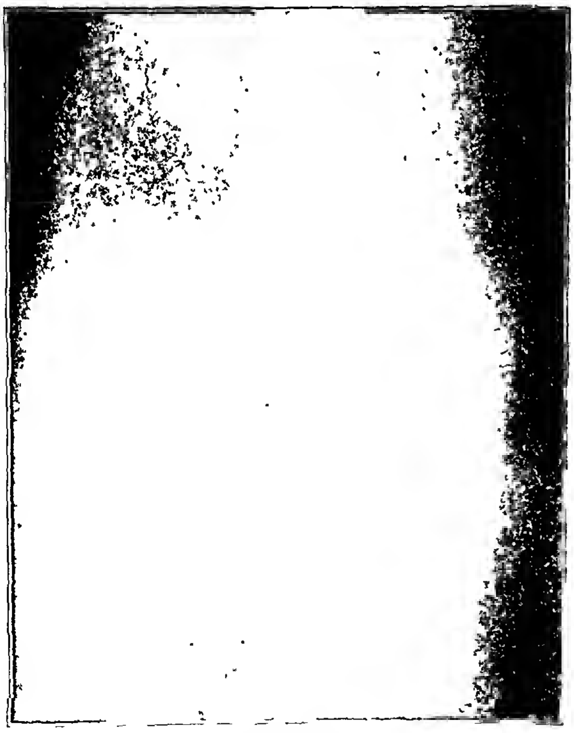

FIG. 9-A

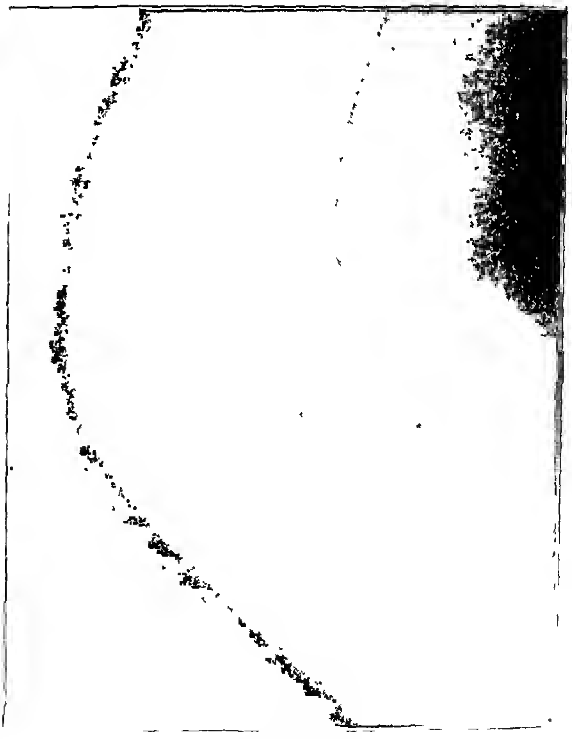

FIG. 9-B

Fig. 9-A: Fracture of the lateral condyle with fracture of half of the capitellum. Anteroposterior view.

Fig. 9-B: Lateral view, showing fracture line extending through the capitellum.

impressive number, since this represents the general run of fractures of the lateral condyle, and the resulting deformities are more progressive and disabling than the deformities due to supracondylar fractures.

Seventeen of these fractures were treated by open reduction and nailing. Poor results occurred in three of these (Fig. 8-A). One fracture was immobilized for one month before operation, because of excessive swelling and cutaneous blisters. The fracture of the condyle was not accurately reduced and subsequent growth disturbances developed. Another patient had a fair reduction, regaining full function of the elbow in six months, and then gradually limitation of movement with crepitation developed. One year later, roentgenograms showed avascular necrosis of the capitellum (Fig. 10-B). In addition to the fracture of the lateral condyle, there was also a fracture line through half of the capitellum, which had escaped earlier recognition (Figs. 9-A and 9-B). There was one other patient with a fracture through the lateral half of the capitellum. This patient was followed only four months and had no circulatory changes at that time.

Four patients of the series with lateral condylar fractures received no treatment, and non-union was present in all. The condyles were displaced and rotated, but were

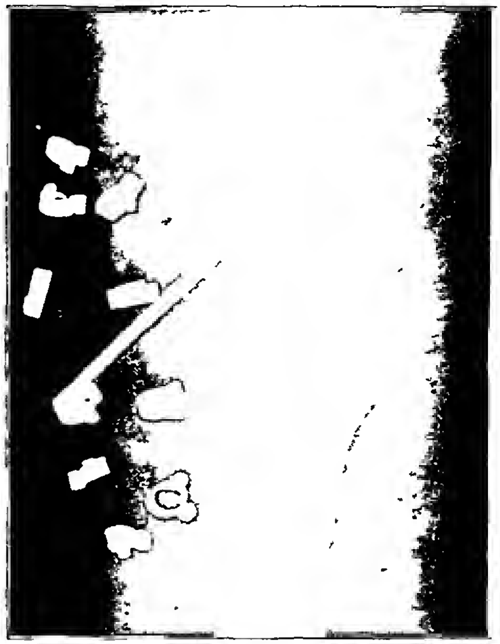

FIG. 10-A

Open reduction with fragments not accurately replaced

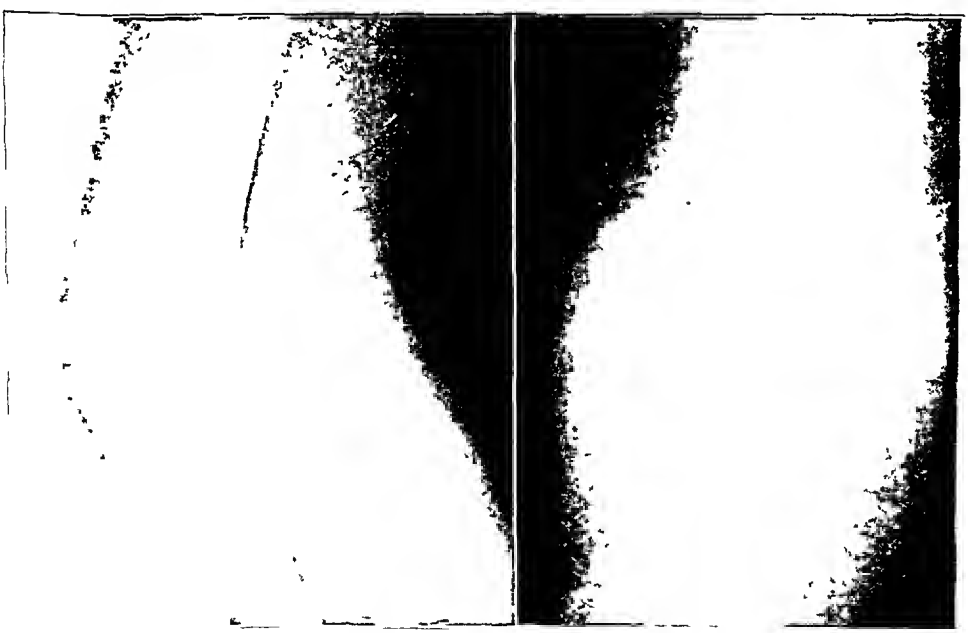

FIG. 10-B

Avascular necrosis of the capitellum and increasing joint disability one year after open reduction and nailing of fracture.

normal in size and displayed no evidence of circulatory disturbance. Two of these patients were followed over a period of twenty years; and, although there was limitation of movement, the lateral stability of the arm was preserved.

A transitory radial palsy developed in one patient following the injury of the elbow; but this disappeared a few weeks after open reduction had been performed.

In two patients of the untreated group, ulnar palsy developed. In both patients it was associated with severe valgus deformity. In four of those treated by closed reduction cubitus varus deformities developed.

Avascular necrosis of the epiphyses of the elbow region is a subject that has received but little recognition. Watson-Jones presents an excellent illustration of this condition in a lateral condyle. No mention of avascular necrosis involving the trochlea could be found.

Phemister reported a six-month-old fracture of the capitellum, in which roentgenograms showed a displaced and rotated fragment that cast shadows of varying density. At operation, the cartilaginous fragment was loosely adherent to the synovial lining, and its base was united to the bone by the underlying cortex. The specimen was found to consist of cartilage which showed very little change. The bone was extremely porous and filled with fatty marrow. Microscopic sections showed that only small parts of trabecular bone remained. This trabecular bone was necrotic, and there was a fibrous invasion of its marrow spaces. This invasion extended to the cartilage, and creeping substitution was present at its periphery. A similar fracture with slight displacement, occurring in a child, resulted in union in ten months.

In children, fractures of the lower end of the humerus which extend through the capitellum or through the trochlea (which is more of an apophysis than an epiphysis) separate the cartilage from its blood supply in the surrounding bone. If a portion of the lateral condyle is attached, the total blood supply lies in the soft tissue attached to this fragment. If, in the course of operative reduction, the soft tissues are removed, the whole fragment will undergo avascular necrosis. Every effort should be made to restore the fragment accurately, without trauma to the soft tissues.

There was one case of fracture of the medial epicondyle associated with a fracture of the olecranon. This fracture was first seen nine years after the original injury. The epiphysis had been avulsed and displaced downward into the joint, with marked disturbance of the medial condyle and non-union of the medial epicondyle. Flexion and extension were limited by 20 degrees. Undoubtedly open reduction would have been the method of choice in treating this fracture. This may not be true of fractures of the medial epicondyle which do not include a part of the medial condyle. An excision of the medial epicondyle rather than an open reduction, is the best procedure in such a case, for its removal does not greatly influence the development of the lower end of the humerus.

SUMMARY

Contrary to prevailing opinion, supracondylar fractures can produce serious growth disturbances if the fracture lines extend into the epiphyseal centers. Cubitus varus and cubitus valgus are not considered serious disabilities, if flexion and extension are complete. However, if the deformity is progressive and is caused by disturbances in the growth centers, disabilities and limitation of motion may occur years after the initial injury.

A satisfactory reduction is one in which the alignment in both planes is good. An anterior or posterior displacement of the fragments, in which the articular surfaces are displaced to a corresponding degree, will produce permanent limitations of flexion and extension. Lateral displacement above the epiphyses will produce valgus and varus deformities, but a good functional elbow may still result.

Supracondylar fractures in which the fracture line, or part of it, extends into the epiphyses may produce growth disturbances similar to those which result from fractures of

the lateral and medial condyles. If the fragment is intra-articular and not attached to overlying bone and soft tissue, it will undergo avascular necrosis. Supracondylar fractures of this type should have an accurate anatomical reduction; and, if the fragments are displaced and rotated, an open reduction is probably the best method of obtaining accurate alignment.

A series of lateral condylar fractures, in which there were poor results in 50 per cent. of the cases treated by closed reduction, speaks for the ineffectiveness of this method. Early open reduction with minimal trauma to soft tissues will give the best results. Avascular necrosis of the capitellum will occur if the fracture line separates the epiphysis from the overlying bone and soft tissues. Fractures of half of the capitellum occurred in two patients with lateral condylar fractures. One had poor apposition by open reduction. and avascular necrosis occurred in one year. In the other, the separation was not complete. the position was good, and healing was uneventful.

Avascular necrosis of the trochlea may occur later. despite a good reduction of a supracondylar fracture. It can cause stiffness at the joint. due to thinning of the cartilage and distortion of the articular surface of the humerus.

Delayed ulnar palsy may cause progressive growth disturbances. and was present in two cases of severe cubitus valgus deformity.

Fracture of the medial epicondyle will not cause a serious disability unless the fragment enters the joint cavity. Non-union is difficult to avoid in closed reduction.

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DISCUSSION

DR. EDWIN W. RYERSON, CHICAGO, ILLINOIS: This is a very important paper. I had no idea there was such a high percentage of bad results in elbow fractures in children. Dr. Wilson finds that about 50 per cent. in the cases that he has seen have been poor; that is appalling. Though I have always been an advocate of not doing open reductions on fractures, if a good result is possible without operation, I shall certainly change my viewpoint after seeing this demonstration. It is evidently necessary to repair by operation the malposition in many of these fractures. As I looked at the roentgenograms, it seemed to me that a large proportion of these fractures could have been adequately reduced and successful results could have been obtained by the use of a hanging cast; and yet a hanging cast is not so successful in giving traction to a small child's elbow, because small children are not standing up all the time, and when they lie down, the hanging cast does not produce any traction. I think many more such patients will have to be operated upon. I have been much impressed with the use of stainless-steel wires which are threaded into the proper position and are cut off flush with the bone. This has been done for years by Compere and Phemister and many of their men with good results. Even though we have penicillin and the sulfonamides, there will be some infections if we leave wires sticking through the skin.

DR. T. CAMPBELL THOMPSON, NEW YORK, N. Y.: This presentation is most appropriate as these fractures have generally been treated much too casually. It is evident from Dr. McDonnell and Dr. Wilson's study that such fractures require skillful treatment. It is our belief that all patients with elbow fractures, except possibly those of the radial head, should be admitted to the hospital for a short period to check the reduction and avoid complications. One case of Volkmann's contracture is just one too many. I should be interested to hear how the one case in this series happened to occur. No credit can be claimed for a good reduction of an elbow fracture if the irreversible reaction of fibrosis of the structures in the forearm and loss of function in the hand has occurred.

The use of traction, as described by Dr. Dunlop, as a method of primary treatment in fractures through the condyles and close to the elbow joint should always be considered a method of primary treatment rather than one used only when manipulation fails.

In regard to fractures of the external condyle and capitellum, it is evident that early open reduction is the method of choice. Some surgeons maintain that they can reduce these fractures by manipulation, but many of us are not so dexterous. An early open reduction is indicated in these cases just as much as in fractures of the patella or olecranon where muscle pull is bound to displace a fragment. Certainly the fracture should be accurately reduced and the fragment firmly fixed, leaving the soft tissues attached to it in order to preserve its circulation.

I should like to show the roentgenograms in a complicated case where such a procedure was not possible. In the ten-year follow-up it was interesting to see what has happened to the fragment, which included the entire capitellum, after it had been completely removed and replaced. For a time I thought this epiphysis was actually growing, but now I am not sure. I should like to ask Dr. Wilson what procedure he would suggest in such a case.

On June 23, 1937, this boy fell on his outstretched arm and sustained a fracture of the external condyle with medial dislocation of the forearm and humerus. The fracture was reduced elsewhere and the arm was immobilized in plaster for four and one-half weeks. Seven weeks after injury, August 12, 1937, the boy was admitted to the hospital with complete disarrangement of the bony landmarks about the elbow and motion of 80 to 105 degrees. Pronation and supination were limited, and there were ulnar-nerve symptoms. X-rays showed medial displacement of the radius and ulna and rotation of the external condyle. On August 14, through a posterior arthroplasty incision, the soft tissues were stretched freely and the dislocation was reduced. The external condyle had to be entirely separated from the extensor muscles in order to replace it. It was held in position with a bone peg. The postoperative course was uneventful. Three months postoperatively, movement was improving rapidly (45 to 125 degrees) and pronation and supination were complete. At the end of three years the flexion was perfect. Extension was limited to from 20 to 145 degrees. Pronation and supination were normal. X-rays taken on January 14, 1947, ten years after the operation, showed a 15-degree increase in the carrying angle; motion of from 25 to 150 degrees was present.

Dr. J. S. Speed, Memphis, Tennessee: I think this is too important a subject to pass over without some positive remarks being made with regard to it. Dr. Wilson's paper clearly illustrates the fact that open reduction is the only way to treat fractures of the lateral condyle. Poor results in 50 per cent. of these cases illustrate the necessity for doing something immediately when these fractures occur. We reviewed our cases many years ago and found that, in the vast majority of them, we could not reduce these fractures by closed manipulation. If you want to get the best results in a large number of cases do an immediate open operation.

Dr. Thompson's case illustrates the point that the time to do the reduction is immediately. After three or four weeks the opportunity to restore a normal elbow has been lost, because the blood supply to these fragments cannot be preserved if the elbow is operated upon late. To mobilize the fragment you have to take off the soft tissues,—thereby interfering with the blood supply. I would like to make a plea for immediate reduction with internal fixation in all fractures of the capitellum in children.

Dr. John C. Wilson (closing): I wish to thank the gentlemen for their interesting discussion. The late circulatory changes which occurred in the fracture fragments proved to be the most fascinating part of this study. These are associated with rather bizarre growth disturbances. It is disconcerting to reduce a fracture, tell the parents everything will go well, and then have the patient return in a few years with a severe deformity. Sufficient attention has not been directed to the fact that changes in circulation do occur, and, if severe, will cause changes in the articular surfaces which may result in limited motion of the joint.

It is believed that excision of the capitellum is not a good procedure. Even though it does not unite, it acts as a buttress to prevent deformity of the elbow. This has been exemplified very well in the slides shown by Dr. Thompson, and it occurred in two instances in the series of patients studied.

THE CINEPLASTIC METHOD IN UPPER-EXTREMITY AMPUTATIONS *

BY RUFUS H. ALLDREDGE, M.D., NEW ORLEANS, LOUISIANA

Recent renewal of interest in amputations and artificial limbs has resulted in the accumulation of additional information on the cineplastic amputation and prosthesis, which, if properly considered, may eventually increase the usefulness of this method. This information includes recent developments in the surgery of the method, as well as more knowledge of the shortcomings of the old type of prosthesis and principles which newer prostheses should incorporate.

Sauerbruch's cineplastic method is the only one which has survived, and it is well known everywhere, having been in use for over thirty years. The purpose of this paper is to review some of the important principles of the surgery and prosthesis, learned in this country and in Germany during the past year. The work in Germany was observed by the Army Surgeon General's European Commission on Amputations and Prostheses**, early in 1946. Since that time, considerable work has been done on the prosthesis by the Committee on Artificial Limbs of the National Research Council.

The Cineplastic Method in Germany

The greater part of the cineplastic work in Germany has been done in two centers, each with complete shop facilities for prostheses, located in the hospitals in which the surgery is done. F. Sauerbruch himself was actively in charge of the work at *Charite Krankenhaus* in Berlin, and Prof. Max Lebsche was the surgeon in charge of this work at several hospitals in Munich, including the *Chirurgische Klinik* of the University of Munich. Several thousand cineplastic operations were done on World War II amputees in these two centers. Patients were usually given a choice of the cineplastic method, the Krukenberg operation, or the conventional methods not requiring special operative procedures. No particular method was urged upon any patient. The Krukenberg method was commonly used on below-the-elbow amputations by many surgeons, particularly for bilateral amputees. One reason for this was that, with the Krukenberg method, a prosthesis was not required. For some bilateral amputees, the cineplastic method was used on one side and the Krukenberg method on the other. Many amputees in cineplastic centers, where prostheses were available for the cineplastic amputation, chose the Krukenberg method. Many others, particularly unilateral amputees under the same circumstances, preferred the conventional methods which usually included the use of the work arm.

In Berlin, the cineplastic method was used exclusively at *Charite Krankenhaus* by Sauerbruch. Those desiring the Krukenberg method were cared for at the *Oscar Helene Heim;* there over five hundred Krukenberg operations had been done, the majority on bilateral cases, and over fifty of these on blind bilateral amputees. In Munich, Lebsche used all methods, according to the needs and desires of the individual patients.

The results of cineplastic surgery in the patients seen were generally excellent. Complications were rare, and the muscle motors had good excursion and strength. Sauerbruch had continued to use the standard technique, but Lebsche had introduced a modification which seemed to give improved results without unduly complicating the procedure. In addition to the use of the usual Sauerbruch technique, he had practised liberation or division of the distal insertion or attachment of the muscle through which the tunnel was placed. This modification had been used by Lebsche on over five hundred cases during the

*Read at the Annual Meeting of The American Orthopaedic Association, Hot Springs, Virginia, June 27, 1947.

** Members: Leonard T. Peterson, M.D., Paul E. Klopsteg, Ph.D., Rufus H. Alldredge, M.D., E. M. Wagner, and R. G. F. Lewis.

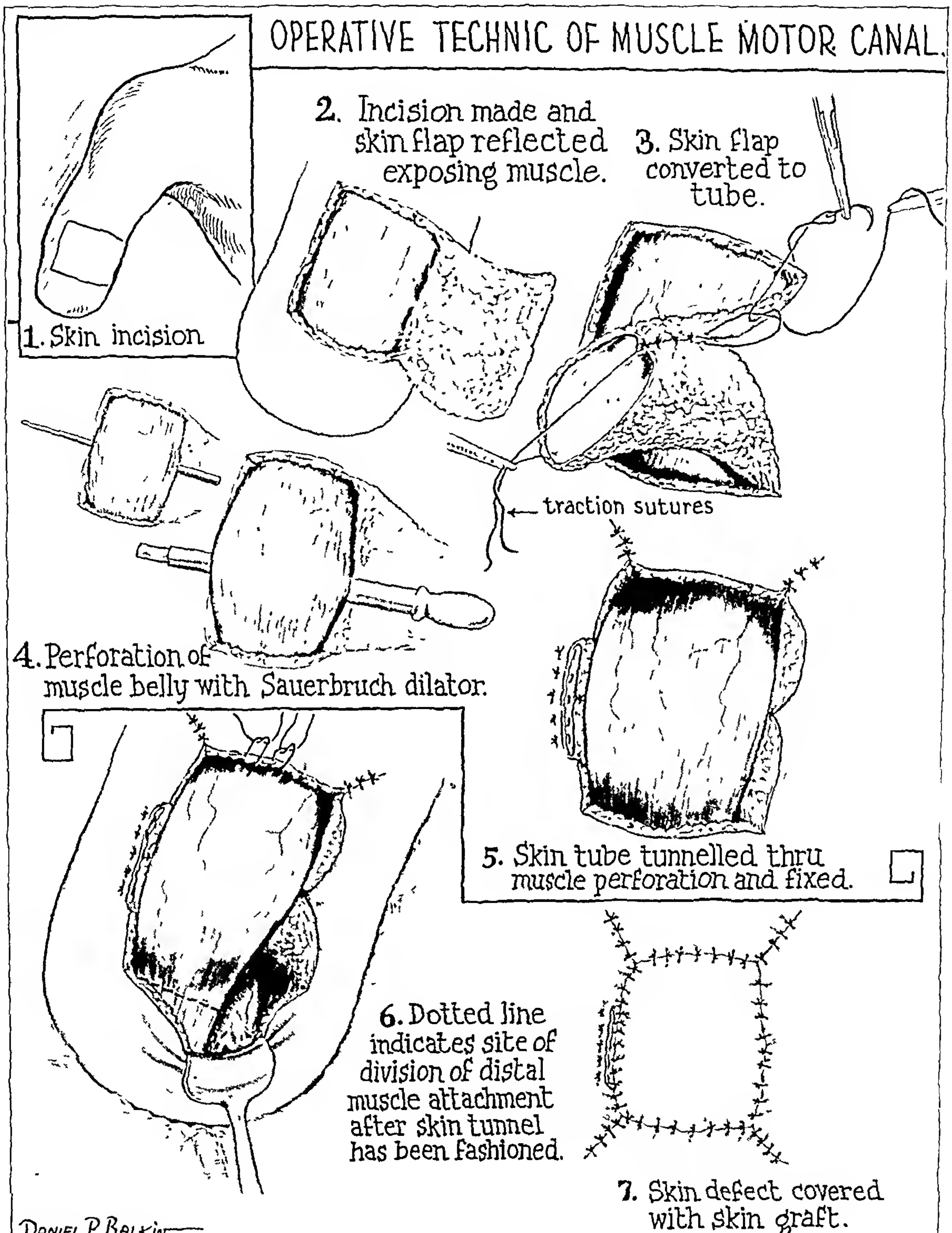

FIG. 1

Surgical technique of cineplastic muscle-motor construction.

three-year period from 1943 to 1946. Many of the results were seen in all postoperative stages, and a definite impression was gained that the muscle motors had more strength and excursion, and that they could be better controlled by the patient, than any seen elsewhere. A number of patients operated upon elsewhere by the standard technique were seen in Munich before and after further surgery was carried out by Lebsche to liberate the distal muscle attachments. These patients were definitely improved by this additional procedure.

The German cineplastic prosthesis was essentially the same as that originally developed by Sauerbruch and his associates. It lacked many desirable cosmetic, functional, and mechanical features.

Principles of the Cineplastic Method

The cineplastic method of Sauerbruch has been described in this country in numerous articles by Kessler and in a monograph by Nissen and Bergmann. It is not necessary to repeat much of what has been said in these excellent writings; those who are interested are referred to them for further details.

The distal ends of the muscles of the stump are canalized by the use of skin tubes. Usually two are employed, one through the flexor muscles and one through the extensors. After sound surgical healing has taken place, a rod passed through the skin-lined muscle canal or tube is activated by contraction of the muscle. The rod is connected to the prosthesis from each end; and the flexor muscle motor thus acts upon the artificial hand to close it, while the extensor performs the opposite function.

Preoperative Care

The preoperative care of the patient consists chiefly in the use of exercises to develop fully the muscles of the remaining arm stump and those which act upon it. All of the muscles are thoroughly exercised, and the patient is taught to develop active use of the muscles through which the muscle tunnels will be placed. Patients who have actively used the muscles of the stump in their daily activities may not need any special exercises, but a period of from one to six weeks may be required for proper muscle development.

Principles and Technique of Cineplastic Surgery

Cineplastic operations in Germany are performed with the use of local infiltration anaesthesia exclusively. No tourniquet is used. This enables the patient to cooperate fully with the surgeon in properly carrying out the operation. After the limb has been adequately prepared, draped, and anaesthetized, the patient is instructed to actively contract the muscle through which the skin tube is to be placed. This materially assists the surgeon in locating exactly the most desirable site of incision for the skin flap from which the tube is to be constructed. The skin flap is planned in such a way that, when it has been converted into a tube, the tube will lie at a right angle to the fibers of the muscle through which it is to pass. It should be at the level of the most distal part of the muscle belly which can be used for perforation. The skin flap should be designed so that the tube will be as wide and as short as possible. The size of the skin flap varies at each level, being smaller below the elbow than above.

The incisions for the flap are made on three sides of a square or rectangle. so that a square or rectangular flap is made with its base left attached. The two parallel incisions are made transverse to the axis of the muscle fibers to be perforated. All three incisions extend through the subcutaneous tissue and fat, and the deep layer of fascia. All of these structures are then undercut and reflected as a flap to the base, which is carefully left intact.

The flap is planned so that its base is toward the side of the arm having the best circulation. Below the elbow the base is toward the radial side, and above the elbow it is toward the medial side. For the pectoral flap, the base is toward the axilla. When two muscle motors are to be used, they may be constructed at the same operation and the bases of both flaps may be toward the same side, even if they are at the same level of the stump. The bases of skin flaps may be planned in the opposite directions if scars are present which might interfere with circulation to the flaps.

The elevated skin flap is suspended and held taut by the use of two stay sutures, while the surgeon sutures the edges of the flap together to form a tube, using interrupted extracutaneous, non-absorbable sutures (Fig. 1). The suture line is started at the free end of the tube, and is continued toward the base of the flap until the skin edges will no longer come together. The underlying muscle belly is then held by the operator with the thumb

and finger of the left hand, while the muscle is perforated with the muscle dilator (Fig. 1)! The muscle perforation must be larger than the skin tube, but under no circumstances should the perforator be pushed far enough to rupture the muscle. The perforation is never made through tendons, and it is important that it extend through the muscle and not between muscles. The muscle is perforated in such a way that one-third to one-half of the muscle belly is left over the superficial surface of the tunnel. The skin tube is pulled through the muscle tunnel by the use of the stay sutures originally applied. The tube is then rotated

Fig. 2-A

Photograph of bilateral forearm amputee. Bilateral forearm flexor and extensor muscle motors have removable ivory pegs through tunnels

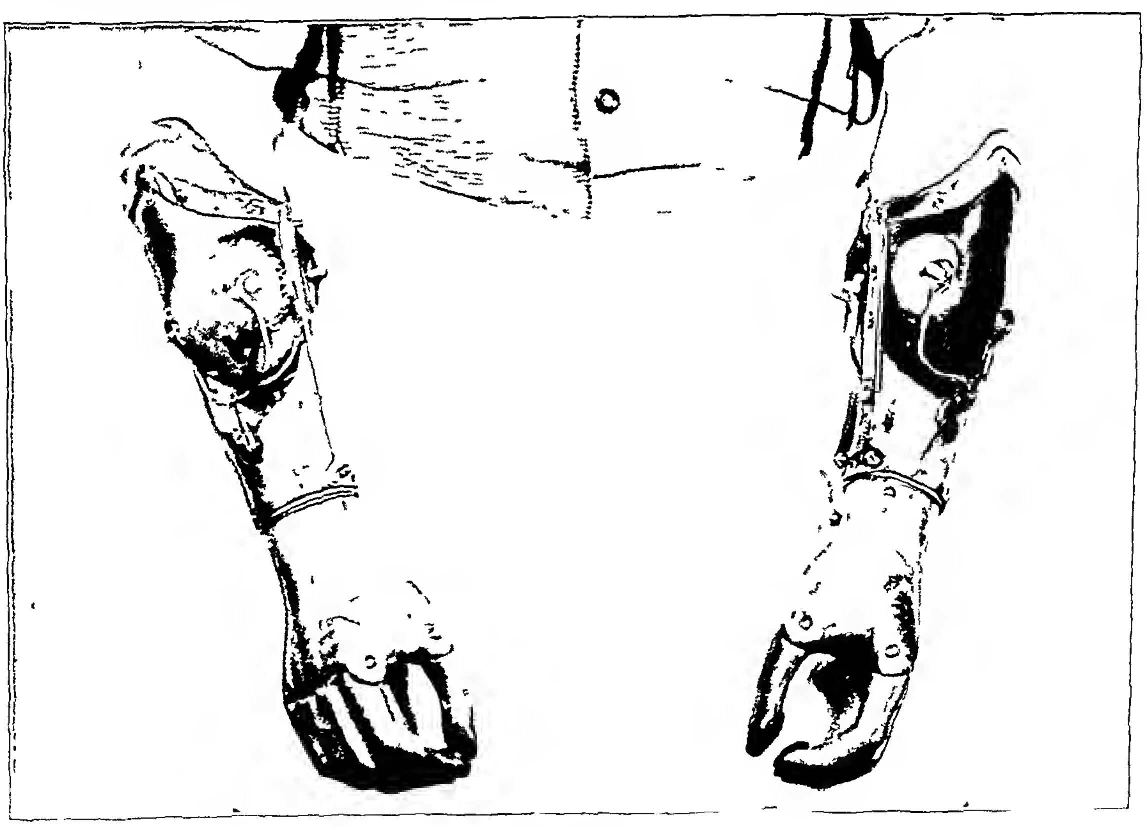

Fig. 2-B

After application of prostheses. (Both surgery and prostheses were German.)

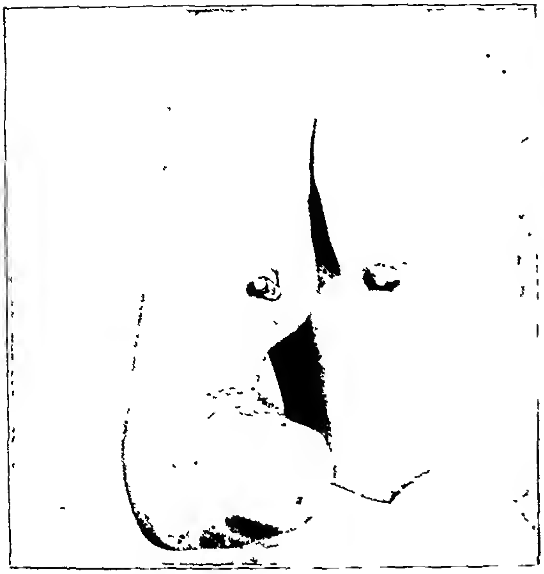

FIG. 3-A

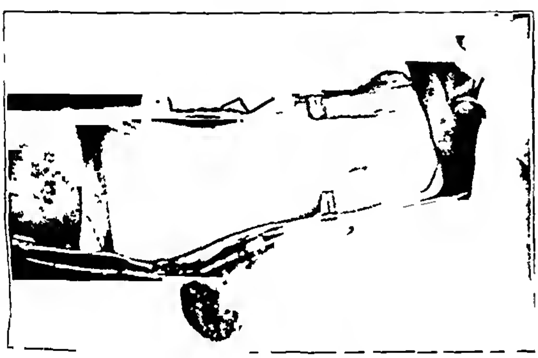

FIG. 3-B

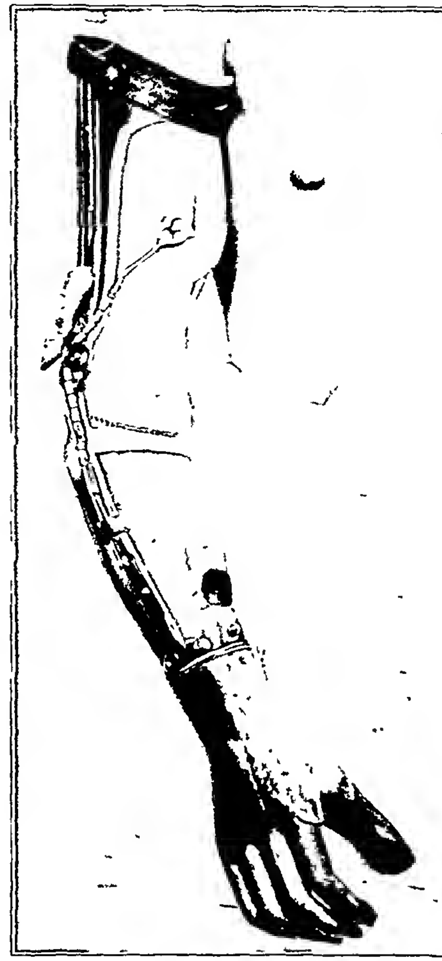

FIG. 3-C

Fig. 3-A: Biceps muscle motor for short below-the-elbow amputation.
Fig. 3-B: Front view, showing attachment of prosthesis to ivory rod.
Fig. 3-C: Prosthesis is attached. (The surgery and prosthesis are German.)

proximally 90 degrees at the distal end, so that the suture line is placed on the proximal side of the tube. This removes the suture line from the pressure of the rod when the prosthesis is used. The end of the skin tube is then sutured to the center of the nearby free edge of the skin. If the tube is found to be longer than necessary, it may be shortened by removing some sutures and spreading out the open end of the tube over the underlying muscle. This also helps to cover the denuded area.

This is the point at which the distal muscle attachment is liberated when Lebsche's technique is used. The muscles can be freed up or the tendons can be divided by undercutting and retracting the distal free skin edge. The remaining open wound is closed as much as possible by skin sutures at the sides and corners. The free skin edges are sutured subcutaneously, directly to the exposed muscle. The remaining area is covered by a skin graft, 0.025 to 0.028 of an inch thick. After the graft has been sutured in place, a pressure dressing is applied without the use of a splint. The skin tube is left empty until wound healing has taken place.

In the construction of the biceps muscle motor, where the full length of the biceps is present, it is important to plan the flap so that the tube formed from it will be at a higher level than the distal end of the biceps muscle belly, while the distal tendon is attached. The muscle is perforated, as usual, through the distal end of the muscle fibers,

which is considerably distal to the level of the skin tube. The elbow is then flexed to bring the biceps perforation proximally to the level of the skin tube, so that the tube can easily be placed through the muscle opening without undue tension or stretch on the tube. The biceps tendon and the lacertus fibrosus are divided, after which the level of the muscle perforation permanently moves up to the skin-tube level, as a result of the muscle shortening which takes place when its insertion is liberated. The elbow can then be extended without disturbing the level of the muscle tunnel or the skin tube. The patient has independent action of the elbow and of the biceps motor. After such a procedure, elbow flexion by the brachialis is apparently as strong as it was with the biceps insertion intact.

In construction of the pectoral motor, a separate incision is made over the anterior axillary fold to the insertion of the muscle. This incision is usually four or five inches (ten or twelve centimeters) in length and starts directly at the center of the free edge of skin, from where the skin flap has been raised. After the insertion of the muscle has been released, the incision is closed in the usual way.

Postoperative Care

The dressing is taken off in ten or twelve days, at which time the sutures are removed. A rod, similar to that which is used with the prosthesis, is inserted into the muscle tube;

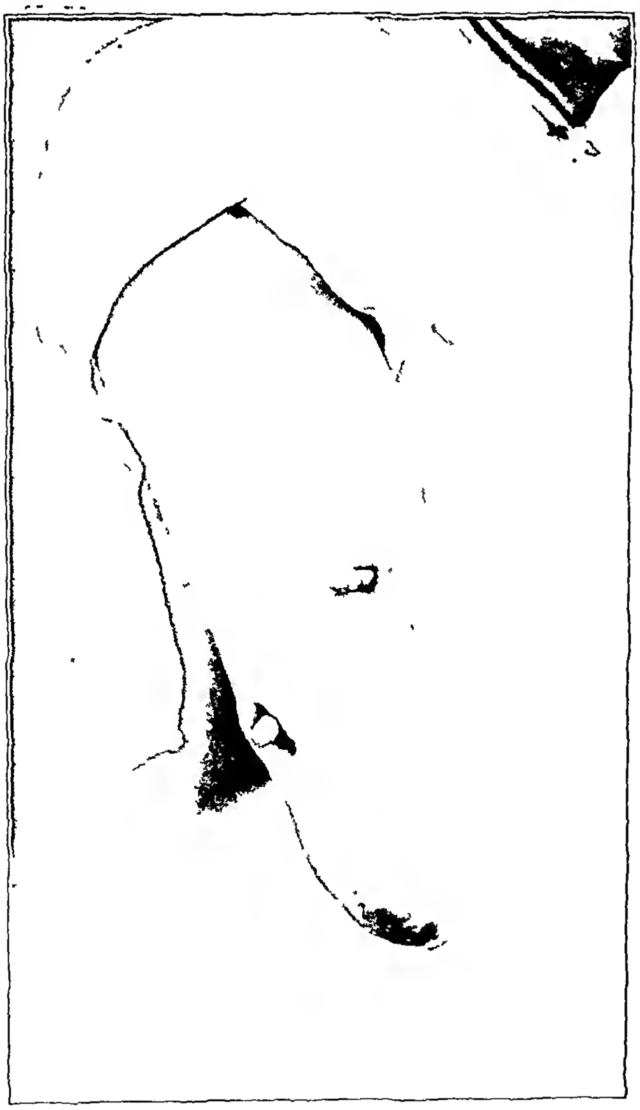

FIG. 4-A

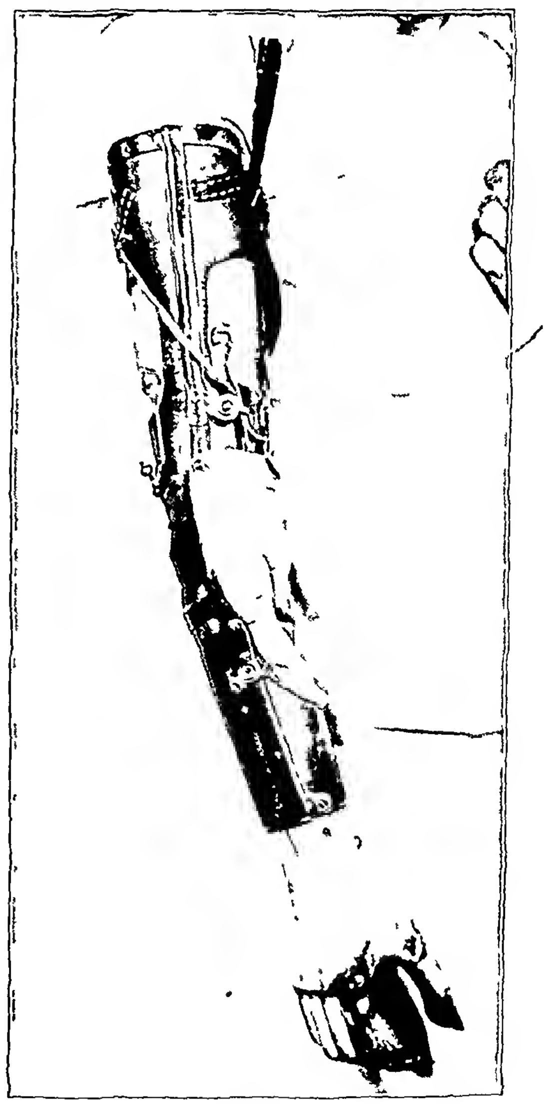

FIG. 4-B

Fig. 4-A: Biceps and triceps muscle motors for amputation through elbow. Cineplastic surgery was performed in 1919 in Germany.
Fig. 4-B: German prosthesis is attached. This patient has used a prosthesis continuously since 1919

FIG 5

FIG 6

Fig 5: Shows harness arrangement for above-the-elbow prosthesis The posterior extension cord of the harness flexes the elbow, and the anterior extension cord supinates the hand of the prosthesis.
Fig 6. The pectoral-muscle motor and prosthesis (Surgery and prosthesis are German.)

and, with the muscle stretched, the patient is instructed to contract the muscle. This procedure is repeated daily until complete healing takes place; thereafter, the patient carries out his own exercises. It is necessary for the exercises to be performed against a pull or stretch on the muscle through the rod. This can be done by the patient or some other individual pulling on the rod enough to stretch the muscle to its full length. Sometimes a weight is suspended from the rod which passes through the muscle tunnel, and the patient exercises the muscle by standing and pulling the weight against gravity. The weight may be increased daily as the power of the muscle increases. These exercises against a pull on the muscle to stretch it are especially important in cases in which the distal muscle attachment has been liberated. The exercises are continued until the prosthesis is fitted. The muscle tubes are cleansed daily with soap and water and alcohol. Powder is not used. A minute sleeve of cotton fabric, similar to stockinette, may be used over the rods to protect the skin tunnels.

Sites of Muscle Motors

The judgment necessary in deciding upon the sites at which muscle motors are to be placed for amputation at the various levels can best be developed from a thorough understanding of the various possible types of prostheses, as well as all other aspects of the method. Faulty placement of the motors may result in complete failure, even though surgery is otherwise carried out properly. The longer the muscle through which the tube is passed, generally the greater will be the excursion of the muscle motor. At best, a muscle motor usually cannot have an excursion greater than half the length of the muscle belly through which it passes. Excursion of the muscle motor is, therefore, determined by the length of the muscle. Excursion is more important than strength. The strength of muscle, unlike excursion, is not related to length, but is in direct proportion to the thickness or diameter of the muscle. The strength of a muscle can be altered by exercises which increase the diameter; but the excursion cannot easily be altered so favorably, since the

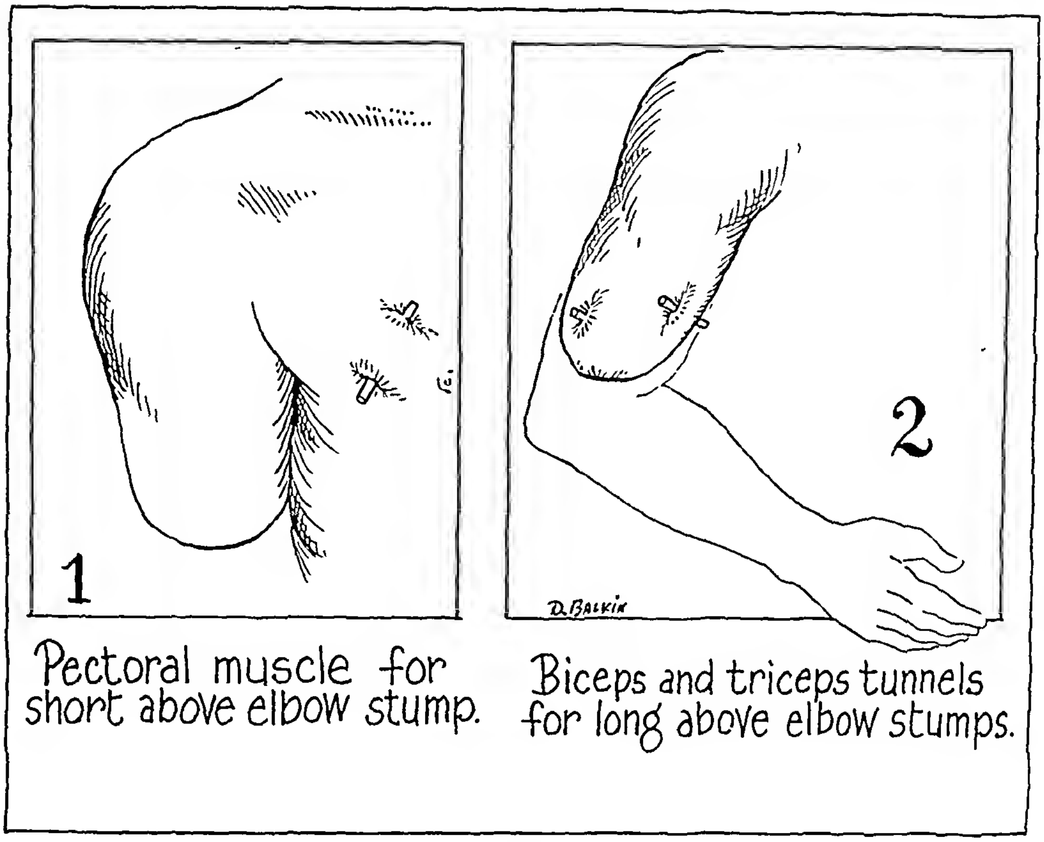

Fig. 7

Sites for muscle motors.

length of the muscle cannot be increased. This means that muscle motors will function better in long stumps than in short ones. Furthermore, patients with long stumps have better control of the prosthesis than those with short stumps.

Generally speaking, muscle motors should not be constructed on stumps which terminate at the level of or proximal to the juncture of the middle and upper thirds of the arm or forearm. In short forearm stumps, the biceps alone or the biceps and triceps are tunneled. When the amputation is higher than the middle third of the upper arm, the pectoral tunnel is used.

Flexor and Extensor Muscle Motors for Forearm Amputations

Usually two muscle motors are used in the forearm stump of good length,—one through the flexor muscles and one through the extensors. The muscle tunnels are placed through the most distal part of the muscle bellies, just above the musculotendinous juncture. The flexor tunnel is placed through the flexor digitorum sublimis, and the extensor tunnel through the extensor digitorum communis. It is important that the tunnels pass through the muscles and not between them.

The best length for a forearm stump is at the level of the lower and middle thirds, or slightly below this level. Amputation through the wrist does not provide a favorable site for cineplasty. The flexor motor closes the artificial hand and the extensor opens it. The prosthesis does not extend above the elbow. Passively operated rotation at the wrist may be locked at any point. There is also a lock to maintain the hand in the closed position for prolonged holding. The flexor motor has more strength and excursion than the extensor; but, since the function of opening the hand is much less important than that of closing it and grasping, this makes little difference. Forearm motors have less strength and excursion than those above the elbow; but this does not detract from the practical result, as the motors are nearer the prosthesis, and the retained elbow function makes the end result at least as good as that in cases in which above-the-elbow motors are used for

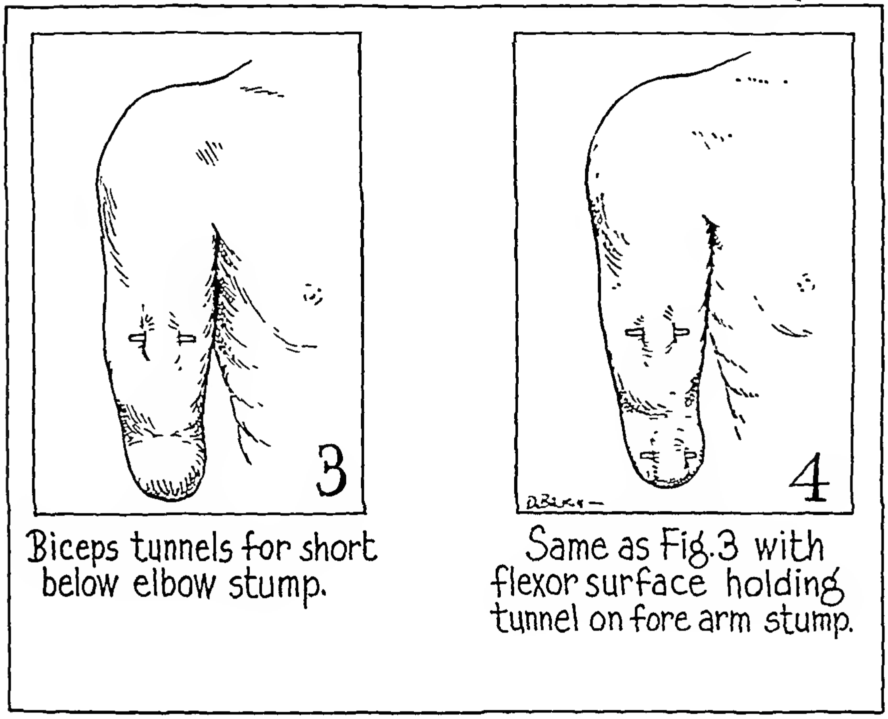

FIG 8

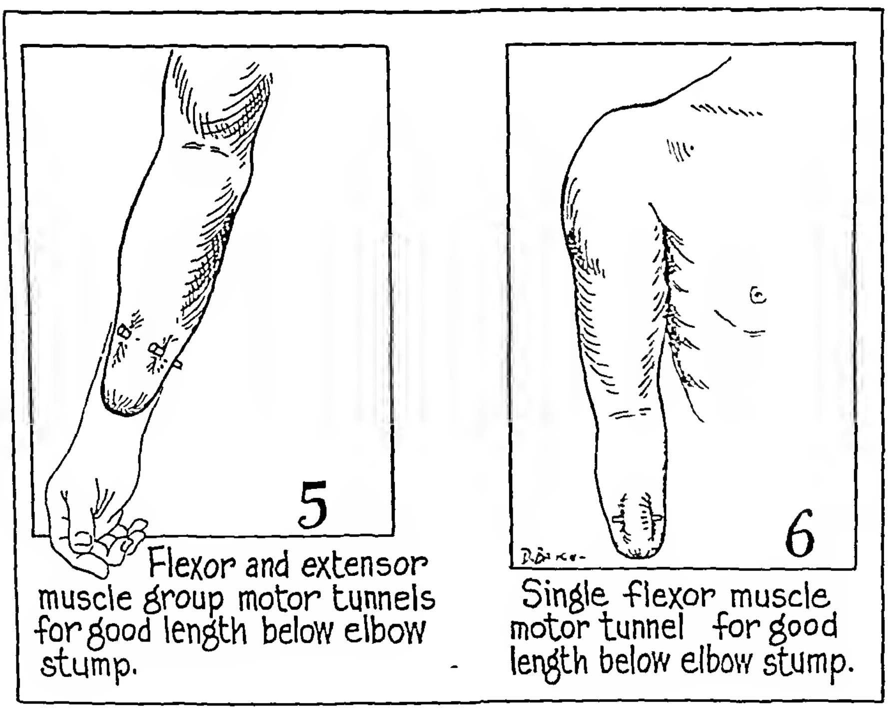

FIG 9

Sites for muscle motors.

above-the-elbow amputations. Forearm motors are best used at a level which corresponds to the ends of the bellies of the muscles through which the tunnels pass, and should not be used in any forearm stump which terminates at the level of or proximal to the juncture of

FIG. 10

The Krukenberg stump in German war wounded. A prosthesis is not usually employed on this type of stump.

the middle and upper thirds of the forearm. The average excursion of the forearm flexor motor is from 1 to 2 centimeters, and that of the extensor is from 1 to 1.5 centimeters. The flexor motor is capable of pulling from fifteen to twenty-five pounds, and the extensor from ten to fifteen pounds.

Flexor Motor Alone on Forearm Stump

Although there are good theoretical reasons for using both the flexor and extensor muscle motors whenever possible, it is not always necessary to do so. The flexor motor alone may be used if the extensors cannot be utilized, or if the patient prefers only one motor. In this case, a spring in the hand performs the function of the extensor motor. A number of patients with single flexor motors of the forearm were observed in Munich; and some patients actually preferred the use of only one, declaring that they could do as much with one motor as others could do with two. With only one motor, it is necessary for a leather strap to be used above the elbow to help suspend the prosthesis; otherwise the prosthesis is the same as that used for double forearm motors.

Biceps and Triceps Motors for Amputations below the Elbow

When the forearm stump is too short for canalization, either a biceps motor alone or a biceps and a triceps motor may be used. Lebsche usually employed the biceps motor alone for short forearm stumps. The results in these cases were among the most impressive of any seen in Germany. Lebsche also used the single biceps motor in many long forearm stumps from choice, in men who had to do work that was heavier than average. The biceps muscle motor, when used for amputations below the elbow, gives the best function of all, whether it is used in conjunction with the triceps motor or alone. When the biceps motor is used alone, it acts on the prosthesis to close the thumb and fingers simultaneously; and a spring opens the hand, instead of the triceps motor. The elbow of the prosthesis is moved by the short stump, which fits into a socket; otherwise the prosthesis is the same as that for forearm flexor and extensor motors. When the triceps motor is used with the biceps, the

former serves to open the hand instead of the spring. The biceps motor has an excursion of from 5 to 7 centimeters and will pull from forty to seventy pounds of weight. The triceps has much less excursion and strength than the biceps.

FIG. 11-A

FIG. 11-B

FIG. 11-C

FIG. 11-D

A bilateral German amputee with two Krukenberg stumps. Surgery was performed six years before the photographs were taken in Berlin, in 1946. This man was the amputee instructor for all patients with Krukenberg stumps at *Oscar Helene Heim* in Berlin, where several hundred Krukenberg operations had been performed. He was completely independent with the use of his stumps.

Biceps and Triceps Muscle Motors for Amputations through and above the Elbow

These motors may be used successfully on amputations through the elbow joint, bu it is necessary for the portion of the prosthesis above the elbow to be elongated by th insertion of the elbow mechanism below the end of the stump. In such a case it is necessar for the forearm part of the prosthesis to be shortened, for equalization of over-all length The site of choice for above-the-elbow amputations is just above the condyles of th humerus. The biceps motor closes the hand and the triceps opens it. In addition, activ supination of the hand at the wrist joint and active flexion of the elbow of the prosthesi are obtained by the use of a shoulder harness. A spring in the artificial hand acts agains supination to return the hand to a resting position of pronation. These muscle motor should not be used on stumps which terminate at the level of or proximal to the junctur of the middle and upper thirds of the arm.

The Pectoral-Muscle Motor

The pectoral motor has the greatest excursion and strength of any motor in the uppe extremity. Excursion ranges from 5 to 9 centimeters, and strength from fifty to over on hundred pounds. Unfortunately, the amputee is unable to control the function of th pectoral motor as well as that of the others, and much of its strength and excursion ar lost in transmission from the motor to the prosthesis. The pectoral-muscle motor ma be used alone on stumps too short for biceps and triceps motors, or in conjunction with biceps and triceps motors. Lebsche has used the pectoral motor in many cases, including some bilateral amputees, and the results have been encouraging enough to justify continuance of its use.

The Holding or Stabilizing Tunnel

In some cases, skin tunnels are constructed purely for the purpose of stabilizing the prosthesis on the arm stump, and they may or may not be passed through part of a muscle. On short below-the-elbow amputations in which the stump tends to become displaced out of the socket of the prosthesis with flexion of the elbow, a skin holding tunnel on the flexor surface of the short stump may aid materially in maintaining the stump in the socket. This type of holding tunnel usually does not pass through the muscle, as no great amount of pull is exerted upon it. Another site for the placement of a holding tunnel is the posterior surface of the above-the-elbow stump, when the pectoral motor is used to move the prosthesis. This tunnel is subject to great stress in offsetting the forward displacement of the prosthesis by the powerful pull of the pectoral motor, and is constructed in the usual way and placed through the muscle.

Muscle Physiology in Relation to Cineplastic Muscle Motors and Prostheses

There has recently been a revival of interest in the physiology of muscle in relation to the requirements of the prosthesis for cineplastic amputations. The University of California workers for the Committee on Artificial Limbs have reviewed muscle physiology and made rather extensive studies of the physiology of the muscles of cineplastic amputees in whom the insertions of the muscles had been divided. Dr. Verne T. Inman has been most interested in these studies; he and his co-workers have made interesting and valuable observations, the implications of which are clear regarding the requirements of the cineplastic prosthesis. Inman and the California workers have studied the dynamics of isolated human muscle in cineplastic amputees, to determine the characteristics of muscle which are essential in the design of a prosthesis by which the potentialities of the muscle can be realized. A definite relationship has been revealed, by studies of isometric muscle tension, between the length of the muscle and its active tension. The greater the muscle length, the greater the tension that can be developed. A study of the ability of the tunneled muscles to shorten

against increasing loads revealed a linear relationship between the load and the distance the muscle could shorten,—the greater the load, the shorter distance the muscle could move it. Attention has been called to the natural compensatory mechanisms in the body, causing the muscle to be used at its most advantageous length. The necessity for the interposition of compensating mechanisms in the prosthesis to mimic those in the body has been pointed out. What is needed, in other words, is not merely a force multiplier which goes into action when a certain amount of pull is applied. Mechanisms must be developed which will maintain the tunneled muscle at its greatest length, throughout the range of motion of the various parts of the prosthesis.

The German prosthesis and its modifications do not incorporate any of the principles suggested by these studies.

SUMMARY

Observations by the Army Surgeon General's European Commission on Amputations and Prostheses early in 1946, and the work of the Committee on Artificial Limbs since that time, have resulted in additional knowledge of the cineplastic method. The only cineplastic method still in use is that of Sauerbruch, developed in Germany during and after World War I. Little was known, until early in 1946, of the status of cineplasty in Germany or of the management of arm amputations in general in that country during and since World War II.

The cineplastic method was found to be in active use chiefly in two centers, Munich and Berlin. Cineplasty was by no means used to the exclusion of other methods, even in these two centers. Patients were usually given their choice of the three methods generally used,—the cineplastic, the Krukenberg, and the conventional methods requiring no special surgical procedures.

Prof. Max Lebsche of Munich introduced the practice of liberating the distal attachment of the canalized muscle in cineplastic operations. This modification seemed to improve the results without unduly complicating the procedure. The surgery of cineplasty was found to be highly developed. It is doubtful if the surgical aspects of the method can be improved appreciably.

The principle of the method consists in the use of two muscle motors on the arm; these are constructed by raising a flap of skin on the stump and converting it into a tube, which is placed through a hole in the muscle belly. When the muscle is contracted by the amputee, the tube is moved. A rod through the tube is connected to the prosthesis. Active contraction of the muscle thus governs the action of the prosthesis through the rod. One muscle motor is constructed on the flexor surface of the arm and the other on the extensor surface.

The selection of the sites for placement of the muscle motors is of the utmost importance. The muscles should be tunneled at the distal end of the muscle fibers. The excursion of the muscle tunnel is in direct proportion to the length of the muscle through which the tube passes. The strength of the motor is in direct proportion to the width or diameter of the muscle belly. The biceps alone or the biceps and triceps should both be canalized for short stumps below the elbow, and the pectoral motor should be used for short arm stumps above the elbow.

The preoperative and postoperative care, consisting chiefly in proper muscle exercises, is highly important. Before operation, all of the muscles are strengthened to the maximum extent, and the patient is taught selective use of those to be tunneled. Following operation, the patient is taught active use of the muscle motors, while the muscles are stretched to their full length. Strength and excursion of the motors are increased by active contraction of the muscle motor against gradually increasing resistance on a rod which passes through the tunnel.

The German prosthesis is still essentially the same as that originally developed,

It is lacking in cosmetic, mechanical, and functional qualities. It is also very delicate, and the component parts are subject to wear and frequent breakage. At present, no prosthesis is known which is essentially different or better than the German one.

Much recent work has been done on the cineplastic method by the Committee on Artificial Limbs. Fundamental research has been carried out on cineplastic amputees, with particular regard to the physiology of the muscle motors in relation to the mechanical needs of the prosthesis. Results of these studies at the University of California have already indicated a definite need for compensatory mechanisms in the prosthesis, to take the place of the natural ones which were lost when amputation was sustained. The incorporation of these and other valuable principles, worked out by the Committee on Artificial Limbs, should improve the future prosthesis appreciably. When this has been done and a better prosthesis has been made available for use in properly organized cineplastic centers, the method may well enjoy more extended use than at present.

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DISCUSSION

Dr. Paul B. Magnuson, Chicago, Illinois: As you know, Dr. Alldredge was Chief of the Amputation Service at one of the Army General Hospitals during the War and was selected by the Army and the Committee on Artificial Limbs of the National Research Council to go to Germany with certain engineers, accompanied by Colonel Peterson of the Army, to investigate the possibilities of improvement of artificial limbs. I think most of Dr. Alldredge's time there was spent in investigating the cineplastic technique. He stayed longer than the rest of the Committee, and came back after studying the possibilities of the cineplastic operation.

The cineplastic operation differs in two ways from the old Sauerbruch method: (1) The muscle is severed from its attachment; and (2) a very much larger tube is made, through which the peg is passed. Both changes seem to be important. The size of the tube is larger and, consequently, the skin lining the tube can be kept in much better condition. The larger the tube and the larger the peg, the less pressure there is on the skin with movement of the apparatus.

The Committee on Artificial Limbs has been trying to devise better prostheses for use in these cineplastic operations, and that is a mechanical problem which has up to now baffled some of our best mechanics. Dr. Inman of the University of California has gathered, in the process of this investigation, some very interesting facts on actual muscle motors. I think I heard him say that he had seen pull of 100 pounds exerted by the biceps in a straight pull. Most of the power exerted is in direct proportion to the length of travel of the muscle. You can develop the breadth of the muscle, but the amount of acceleration depends upon where the peg is placed. It seems to be necessary with most of these prostheses, if we are to get good results, to place the peg right and to choose the right muscles for giving power. Some kind of a booster mechanism will have to be made in order to get extra grip. There are certain other features which Dr. Wilson will bring out.

I have seen Dr. Alldredge do some of these operations. A patient who is willing to work before the

operation will get good results from this cineplastic amputation. We have not forced this operation on anyone. We have asked for volunteers. Some enthusiastic surgeons have done operations without having had the muscles developed previously and without knowing what sort of prosthesis the patient was going to wear. I hope this operation will not become too popular because it is easy to do. Its success will depend upon the following factors: placing the tube in the right place, the development of the muscles before the tube is placed in position, and the development of a proper prosthesis. Just now the poor prosthesis is the great handicap.

Dr. Philip D. Wilson, New York, N. Y.: I want to congratulate Dr. Alldredge on this excellent motion picture, which I think has showed both the surgery and the results in a way that has not been done before. In our enthusiasm for the cineplastic amputation as it is shown today and for the recent developments in Germany, we must not lose sight of the pioneer work that Dr. Henry Kessler did in this country. For many years he was the lone person in this country to do this operation. He went to Germany to learn the technique in the 1920's. He brought back appliances and set up his own bracemaker. This has been purely a philanthropic endeavor on his part.

We are held back by the lack of a suitable appliance. The surgery is much further developed than the prosthesis. Even today, with all the efforts of the Committee on Artificial Limbs, with considerable funds at their disposal, and with considerable scientific talent to call upon, we have been slow to produce a hand that is as good as the one the Germans have been manufacturing for some years. I do not say we are not going to find the answer, because I think we will, but it is very difficult.

The study of the physiology, made by Dr. Inman, is very interesting. I hope, if time permits, that we may hear from him. In 1918 I accompanied the late William Baer to Italy to study and report to the U. S. Army on the cineplastic amputation which was done by Putti. We had many talks with Putti and his associates and with Dr. Vangetti, who originally conceived the procedure. Their procedure was based on tendons rather than on a tunnel. Dr. Putti, following the idea of Sauerbruch, developed a tunnel in the muscle belly, and that has proved better.

The advantages are as follows: First, there is an appliance which the man does not operate with a shoulder strap. Second, there is direct control, which can be separated from other movements of the arm and can be performed with the arm in any position; this is not true of the hand operated with a shoulder strap. Third, the man has a sense of feeling, which comes from deep muscle sensibility, about the size of an object and its form. These are distinct advantages. Certainly if a man were blind, the method would have a great advantage.

I think that, for a man with a bilateral amputation, the cineplastic method holds great promise. Yet I am not sure, from what I have seen, but that a man properly equipped with hooks can do just as much with his hooks as the man with a bilateral amputation who has had the cineplastic method carried out.

The disadvantages lie in the apparatus; its form certainly is bad for the sensitive nature of some of these people. Dr. Baer and I, in our report to the Army in 1918, pointed out, first, that the procedure was still experimental; second, that it should be done only by surgeons who were very familiar with the method and who had the appliance available; and third, that the surgery is still superior to the appliance. I think those conclusions still hold and may be basic.

Dr. Verne T. Inman, San Francisco, California: I wish to thank Dr. Abbott and Dr. Alldredge for the opportunity of discussing for a few minutes the problem of the cineplastic method of amputation. I feel rather deeply about this subject, since on the surface it appears that this method should be a definite step forward in our search for procedures to increase the function of the artificial hand. However, its success so far has been questionable; and I have heard the surgeon put the blame on the limb manufacturer and the limb manufacturer place the blame on the surgeon, because of the inability to develop a prosthesis which would fully exploit the apparent potentialities of the muscle tunnel. Certainly the responsibility rests as much upon the surgeon as upon the prosthesis manufacturer.

One of the reasons why greater success has not been achieved is that surgeons have forgotten many of the fundamental principles of muscle physiology. This is evidenced by the fact that we have permitted the prosthesis manufacturer to construct an arm, based upon the attempted utilization of the muscle directly to move the fingers. We have failed to recognize the presence of a reciprocal relationship between the laws of muscle contraction and the geometry of the joint. A muscle becomes more powerful as it elongates and loses tensile strength as it shortens. In the body, this decrease in strength as the muscle shortens is compensated by changing the effective lever arm or by the separation of origin and insertion during contraction, as exemplified in "two-joint" muscles. The present prostheses fail in not adequately supplying such a compensatory mechanism, with the result that power of grasp is rapidly lost as the artificial hand is closed. There is no hope, as far as I can see, in utilizing the tunnel directly without the insertion of some compensating mechanism which will duplicate to some degree the mechanism of the human body.

LATERAL SKELETAL TRACTION IN THE TREATMENT OF FOREARM FRACTURES *

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The maintenance of the normal width of the interosseous space in fractures of tl shafts of the radius and the ulna has long been recognized as essential. The various methoc of fixation most commonly employed—such as open reduction with subsequent plating (grafting; threading the fragments over a pin; employing mechanical splints, with multipl pin fixation and external-bar splinting; and the use of leverage screws, as described b Carrell—testify to the importance of preventing angulation at the fracture level with resultant loss of supination and pronation. In compound fractures which are draining, an which are not examined until after initial treatment has been started, the orthodo methods are either not applicable, or can be employed only after an unnecessary delay The authors recognize that, since the advent of the sulfonamides and penicillin, ope reduction and metal fixation have been advocated even in the presence of wounds that ar not entirely clean. We believe that this is a procedure involving considerable risk, excep in carefully selected cases. A method that could be employed effectively and safely woul afford obvious advantages.

The secondary closure of wounds which have had careful débridement often may b successfully accomplished within the first week after the injury. This practice would un doubtedly facilitate the healing of wounds, so that in many the introduction of metal a the fracture site would soon be tolerated. However, by that time, callus would be present and an appreciable delay in treating the fractures would have occurred.

In addition, compound fractures are encountered in which there has been sufficien loss of cutaneous tissues to make secondary closure impossible. Such adjuncts as skin-grafting and relaxing incisions may be employed; but these, too, may fail to prepare the tissues for a safe approach to an open reduction of the fragments before they have become fixed in malposition.

We were interested in employing a method whereby the fragments could be controlled at the earliest possible moment without jeopardizing the healing of the wound. The principle adopted involves the use of a cylindrical screw, inserted through the normal skin to one side of the compound wound and fastened to the forearm fragment most closely adducted to the other bone of the forearm. Portable traction is applied to the screw. The deeper fragment serves to elevate the more superficial fragment, and traction is employed until union maintains the desired position. Reductions are easily obtained, and the wound is accessible for dressings, secondary closure, or grafting, while the fracture is uniting.

After employing lateral screw traction on several old, infected forearm fractures, with good results, we were encouraged to attempt the same principle in elective surgery. Too often when metal plates are employed in fractures of the radius and ulna, they must subsequently be removed, after union has been obtained, because of insufficient soft-tissue coverage. The ease with which a single screw, projecting through the skin, may be removed without anaesthesia has obviated the necessity for a second operation.

PROCEDURE

Under novocain or, preferably, pentothal anaesthesia, a stainless-steel screw, of adequate length and with large threads, is inserted into either the distal or the proximal

* Read before the Tri-State Orthopaedic Society, April 19, 1947.

the position of the fragments. Traction is maintained until there is roentgenographic e[vi]dence of bony callus, at which time the screw may be removed and a second cast may b[e] applied if necessary. We believe that traction should be maintained until fairly firm unio[n] is obtained, because of the ever-present danger of a recurrence of deformity by the muscl[e] pull of the pronator quadratus and pronator teres. It is imperative that some contact exist

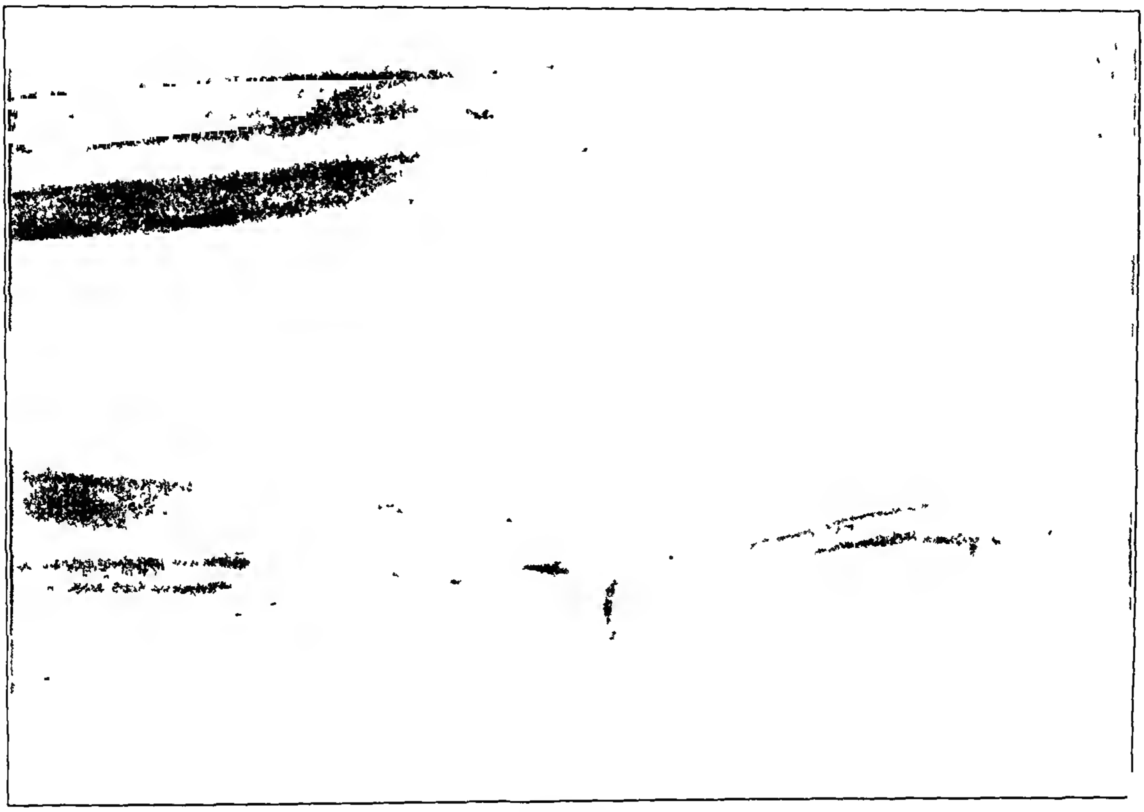

Fig. 2-A

Case 2, G. M. Loss of interosseous space, following compound fracture of radius of fifteen days duration.

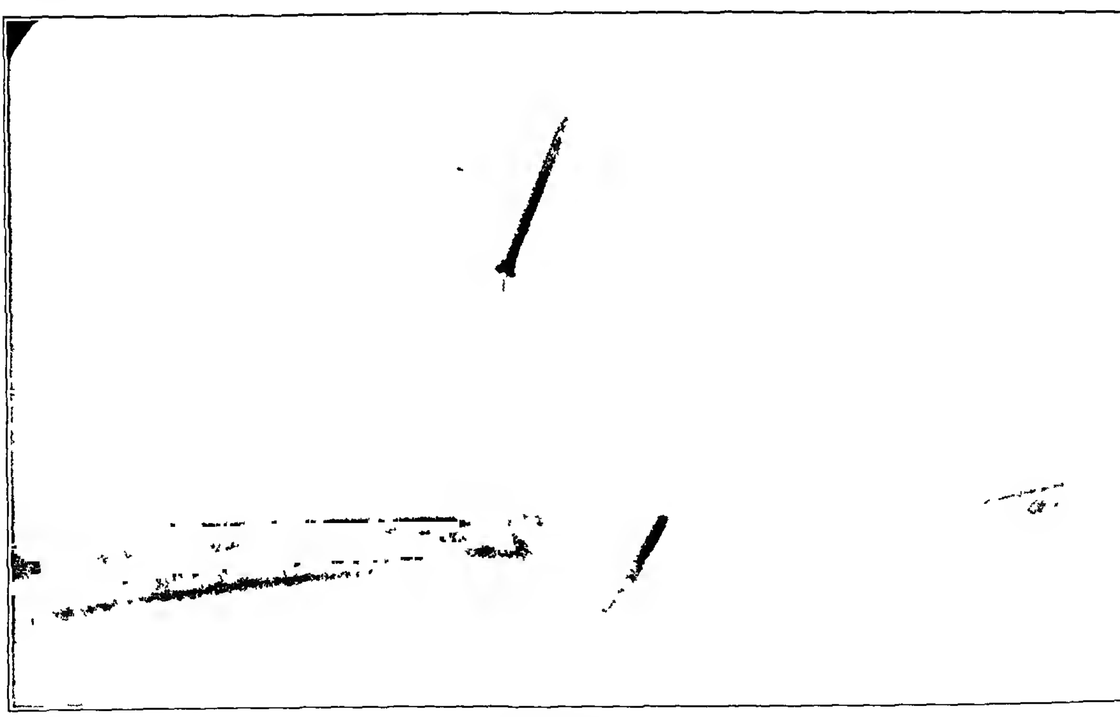

Fig. 2-B

Partial restoration of interosseous space with improvement in position of radial fragments, following five days of traction.

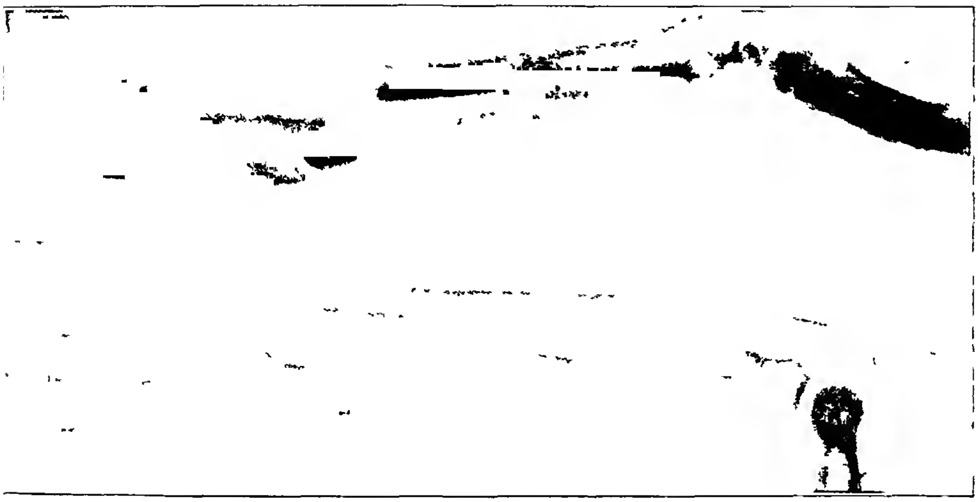

Fig. 3-A

Case 3, D. B. Simple fracture of radius with simple and compound fractures of the ulna.

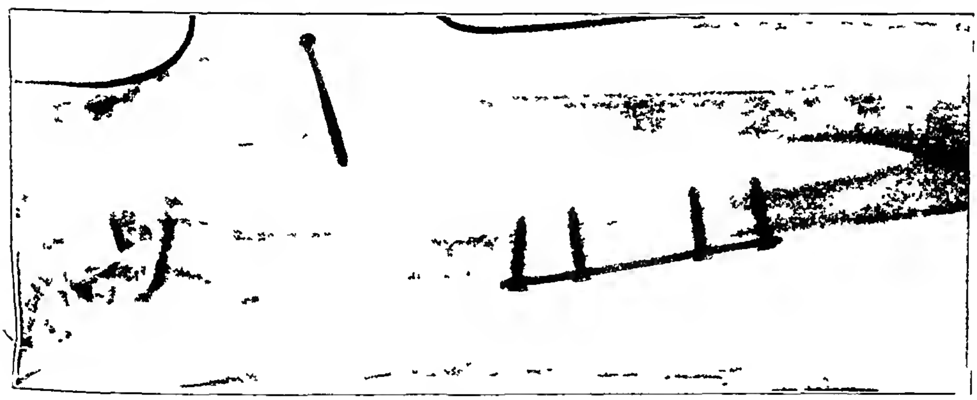

Fig. 3-B

Three days after insertion of plate and screw traction.

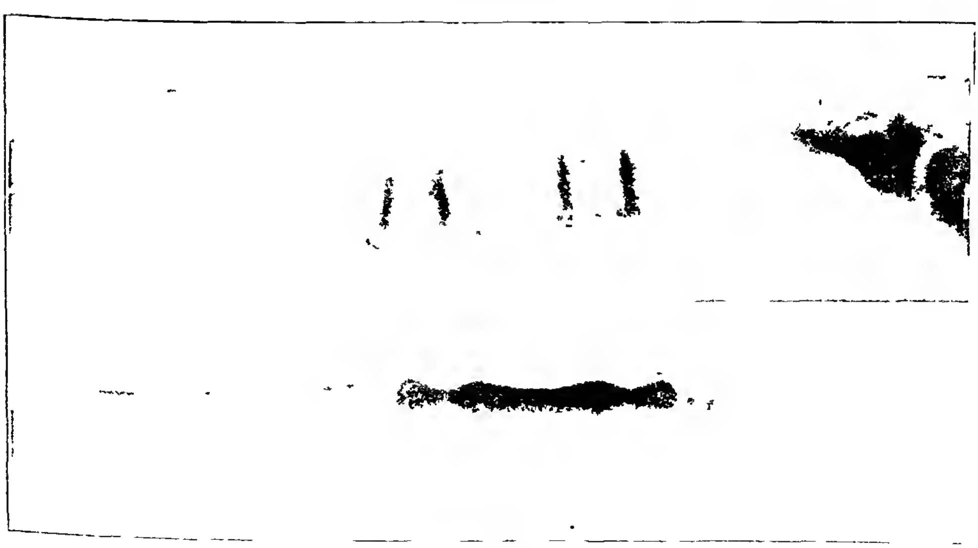

Fig. 3-C

Four weeks after operation, at which time screw was removed and second unpadded long arm cast was applied.

between fragments, inasmuch as complete displacement would result in loss of control of one fragment. However, overpull has not been a problem, because of the limiting effect of the interosseous septum.

CASE 1. W. R., a male, twenty-two years old, entered the Hospital on October 13, 1944, wearing a padded long cast for a rifle-bullet wound of the forearm, received on October 1, 1944. Sulfanilamide had been sprinkled into the wound at the time of injury. The initial surgery, which was carried out elsewhere twenty-

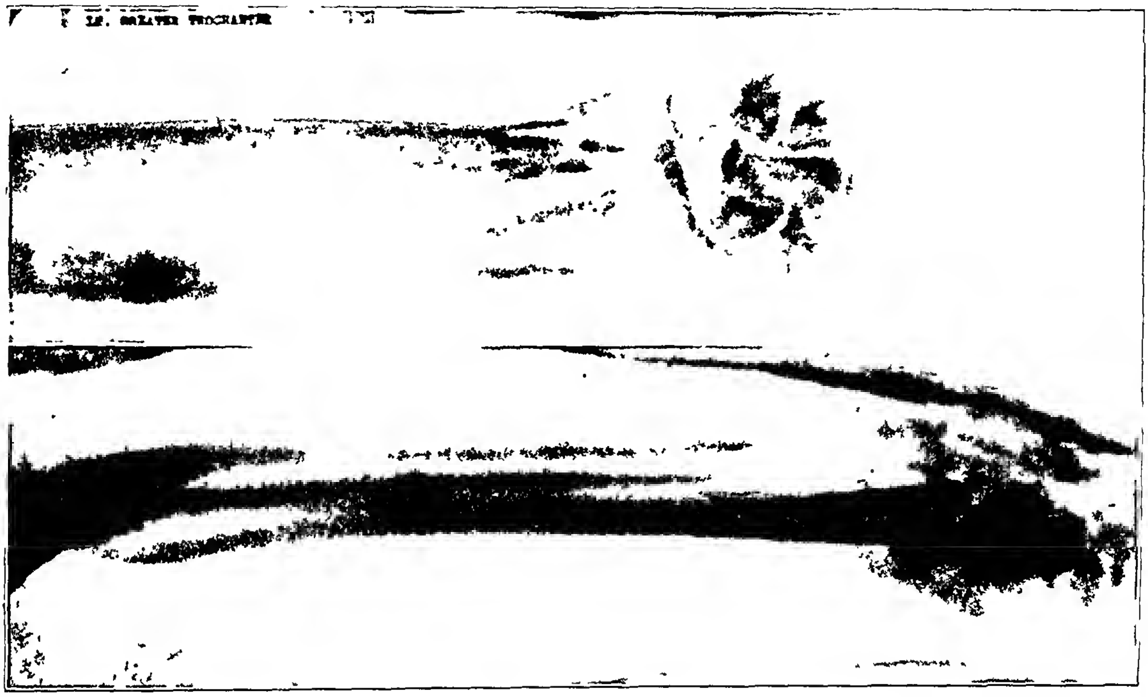

FIG. 4-A

Case 4, H. G. Compound fracture of ulna seventy-two hours after injury. Previous treatment consisted of débridement, packing with vaseline, and application of cast.

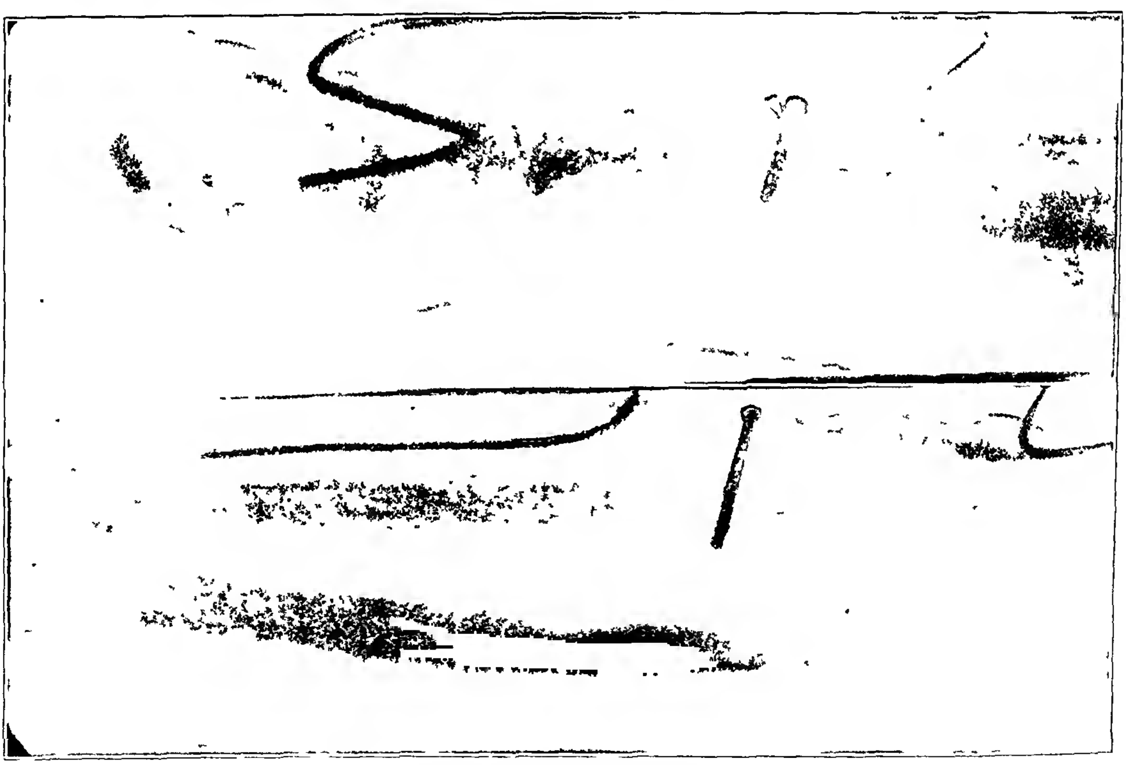

FIG. 4-B

Excellent restoration of interosseous space, following five days of skeletal traction. Screw has been inserted to proper depth.

four hours after the injury, consisted of débridement and fixation in a cast, under pentothal anaesthesia. On October 14, the drainage-soaked cast was removed, revealing an infected wound through the lower forearm. Under sodium-pentothal anaesthesia, a stainless-steel screw was inserted into the distal radial fragment, and gravity traction was instituted by means of a muslin loop around the patient's neck, connected to the head of the screw by a stainless-steel wire loop. On November 6, the screw was removed without anaesthesia, and an unpadded long arm cast was applied. At this time, roentgenographic examination revealed callus and excellent reduction.

FIG. 5-A

Case 5, J. W. Three-month-old Colles's fracture with incomplete radial length and dorsal angulation of distal fragment

CASE 2. G. M., a male, thirty-two years old, entered the Hospital on October 23, 1944, wearing a padded long arm cast for a rifle-bullet wound of the left forearm, which he had received on October 8, 1944. Forty-eight hours after the injury, under pentothal anaesthesia, the "through-and-through" wound had been treated by débridement, dusting of sulfanilamide powder into the wound, and application of a padded, split, long arm cast. On October 24, under sodium-pentothal anaesthesia, the cast was removed, and two foul wounds at the junction of the middle and lower thirds of the forearm were exposed, from which a moderate amount of pus was draining. At this time, a stainless-steel screw was inserted into the radius, and gravity traction was instituted by means of a muslin loop about the patient's neck. On November 14, when there was roentgenographic evidence of callus, the screw was removed without anaesthesia, and an unpadded long arm cast was applied. Good reduction of the radial fragments had been obtained.

CASE 3. D. B., a white male, thirty-three years old, entered the Hospital on May 5, 1945, for a simple fracture of the right radius and a compound fracture of the right ulna, which had been received in an automobile accident, April 23, 1945. Previous treatment had consisted of débridement and application of a cast at another hospital, thirty-six hours after the original injury. On May 8, under sodium-pentothal anaesthesia, open reduction and plating of the radius was done; but, because the ulna had a compound fracture with a draining wound, similar surgery could not be carried out on this bone. Therefore, a stainless-steel screw was inserted into the distal ulnar fragment, and traction was applied by means of rubber bands and a wire bow incorporated in a long arm cast.

FIG. 5-B

Immediately after operation, with reduction of width of interosseous space secondary to osteotomy.

Fig. 5-C

Improvement in radial alignment, following osteotomy and skeletal traction on radius.

On June 5, there was roentgenographic evidence of callus at the fracture site of the ulna; the screw was removed, and an unpadded long arm cast was applied.

Case 4. H. G., a white male, twenty-eight years old, entered the Hospital on June 18, 1945, because of multiple wounds of the left forearm and hip, which had been accidentally received on June 15 while he was destroying enemy ammunition. His previous treatment had consisted of débridement of all wounds, without closure, under pentothal anaesthesia. A padded short arm cast had been applied to the left forearm and wrist. On June 19 the arm cast was removed, revealing a draining, tangential wound, measuring two by four centimeters, with a foul, necrotic base on the ulnar side of the lower forearm. Roentgenograms revealed radial angulation of the ulnar fragments with encroachment into the interosseous space. Under pentothal anaesthesia, lateral traction was instituted with a stainless-steel screw and rubber bands over a padded long arm cast. Follow-up roentgenograms on June 23 revealed the normal width of the interosseous space.

Case 5. J. W., a physician, thirty-five years old, entered the Hospital on January 15, 1946, because of pain, disability, and deformity of the right wrist of three months' duration. On October 13, 1945, the patient fell, suffering simple fractures of the lower end of the radius and the styloid process of the ulna. He stated that, under general anaesthesia, the wrist was manipulated, and a short arm cast was applied which was worn for six weeks. However, roentgenograms, taken on January 16, revealed an incompletely reduced Colles's fracture, with dorsal tilting of the distal fragment and shortening of the radius. Under pentothal anaesthesia, on January 20, osteotomy was performed at the old fracture level, and the dorsal tilting of the distal fragment was corrected. Lateral traction was instituted with a stainless-steel screw and rubber-band traction. On February 8, roentgenographic examination revealed a normal interosseous space: the screw was removed without anaesthesia, and a second long arm cast was applied.

CONCLUSIONS

1. The simple method presented permits early reduction of infected fractures of the radius and ulna. The same principle is now being employed in elective surgery.
2. The use of screw traction has not necessitated any operative attempt to close the original wound.
3. The skeletal traction is discontinued when roentgenographic evidence of callus is present. No anaesthesia has been required to remove the screws.
4. In a small series of cases, there have been no instances of operative infections or overpull.

THE BRIDGING OF BONE DEFECTS

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The bridging of bone defects and bone-grafting for non-union have constituted one of the most important problems of the Orthopaedic Service at Deer Lodge Hospital. This Orthopaedic Treatment Center was organized in April 1944, to treat orthopaedic cases of the three Armed Services, from Manitoba, Western Ontario, and part of Saskatchewan.

From April 15, 1944, to April 15, 1946, 105 patients underwent bone-grafting operations for the repair of bone defects or for non-union of fractures of the extremities. This figure does not include bone grafts for non-union of the carpal scaphoid, or for fusion of damaged joints.

This report has been written, not to extol the merits of any particular graft or technique, but to record the methods used and results obtained at this Center. It is hoped that other Orthopaedic Treatment Centers of the Department of Veterans Affairs will report similar series, so that methods of grafting and results may be compared.

GENERAL OBSERVATIONS

All the patients operated upon were good surgical risks,—young and in good physical condition. This accounts largely for the fact that there were no deaths in the series, although some of the operations, especially those on the upper end of the femur, were quite extensive.

In 85 per cent. of the cases, the injury was caused by a gunshot wound. Accidents of various types, many involving motorcycles, were responsible for the remainder. All but a few of the injuries occurred overseas, and consequently there was an interval of several months between the time of injury and admission to Deer Lodge Hospital.

In the majority of cases, the wounds had either healed or were healing at the time of admission. If a draining sinus was present, an exploration was usually necessary for the removal of a sequestrum, bits of battle dress, or sometimes suture material. In cases in which the wound had healed shortly after secondary suture in the hospitals overseas, three months was the minimum interval allowed between wound healing and the bone-grafting operation. Where there had been a chronic discharging sinus, necessitating exploration, a longer interval—usually from four to five months—elapsed before bone surgery was undertaken. This period is considerably shorter than that allowed after World War I, but it was felt that, because of the more rapid wound healing obtained and the availability of penicillin, the shorter period was justifiable. This proved to be the case, as no failures or loss of the graft resulted from infection in the operative wound in any of the cases which had been healed for three months or more before operation. It is probable that this was due to the routine use of penicillin for several days after every bone-graft operation. This procedure was felt to be justified by the fact that 85 per cent. of the patients had compound fractures resulting from gunshot; and the inconvenience of penicillin administration in the other cases was more than compensated for by the protection gained.

Many of the patients with gunshot wounds had considerable soft-tissue damage, with loss of muscle and scarring of the skin. When it was felt that the operation could

not be done without interfering with the blood supply to a scar near the proposed incision, plastic skin procedures were first carried out, to replace the scar with full-thickness skin. Although the danger of sloughing of scar tissue was appreciated at all times, and procedures were planned accordingly, such sloughing did occur in a few cases, with partial or complete loss of the graft.

Most of the patients with involvement of the femur had been treated by skeletal traction for several weeks prior to immobilization in a plaster spica. Several had tracks of infection where the pin had been inserted; these had to be treated before bone surgery could be done. Healing was accomplished by curetting the infected area and keeping it open with vaseline gauze while it filled in, or by saucerizing the track and allowing soft tissue to fall into it. More of such infections were encountered than had been expected. In most of the cases, a Steinmann pin had been used rather than a Kirschner wire; and it is felt that the larger diameter of the Steinmann pin may have made it easier for organisms to gain access to the bone. Where possible, it seems safer to use a Kirschner wire for skeletal traction.

In all cases of delayed union in fractures of the long bones of the extremities, the limb had been immobilized for at least six months before operation was considered. Unless some union was demonstrable at the end of this period, a bone graft was felt to be indicated to hasten recovery.

Where external immobilization was considered necessary to protect the grafts, plaster-of-Paris splints were used. A padded plaster was applied at the time of operation, and was replaced in from two to three weeks by a skin-tight plaster. For all grafts to the radius and ulna, the plaster extended from the axilla to the metacarpal heads. For grafts to the humerus, a shoulder spica was considered advisable, in view of the fact that these patients were young. A single hip spica was used after bone transplants to the femur; and, if this was considered insufficient immobilization, it was replaced by a double spica, reaching to the knee on the sound side and to the toes on the affected side. For the tibia, plaster extending from the groin to the metatarsal heads was used routinely. These splints were not discarded until the roentgenograms showed that union was well advanced. When the plaster had been removed from the patients with arm grafts, active movements of the joints which had been immobilized were started at once. When the femur was involved, the graft was protected by an ischium-bearing walking caliper for several weeks after removal of the spica, with active non-weight-bearing exercises for the muscles and joints. Following removal of the plaster for a tibial graft, the patient usually walked with crutches for a short time, while doing active non-weight-bearing exercises. When roentgenograms showed that the tibia was strong enough for full weight-bearing, the crutches were discarded.

Tribute must be paid to the medical officers who treated these patients overseas. No gross bone infections were seen at this Hospital. Very few cases of malunion requiring osteotomy were encountered, and length had been maintained satisfactorily in cases with considerable defect in the shaft of one of the long bones. The soft-tissue wounds had all been sutured within a few days, whenever possible, so that soft-tissue scarring was kept at a minimum. All this made the final reconstructive surgery considerably easier.

METHODS OF BONE-GRAFTING

Early in the series, the cortical inlay or onlay graft, with some cancellous bone from the upper end of the tibia, was used in almost every case. Later, when more had been learned about iliac cancellous bone, this type of graft was used more frequently, either by itself or in combination with other methods.

The cortical onlay graft was used twenty-nine times, in the following bones: ulna five, radius two, humerus ten, clavicle two, and femur ten. The technique used was similar to that described by many authors [4,5,6,8,11]. The area of fracture or the bone defect was ex-

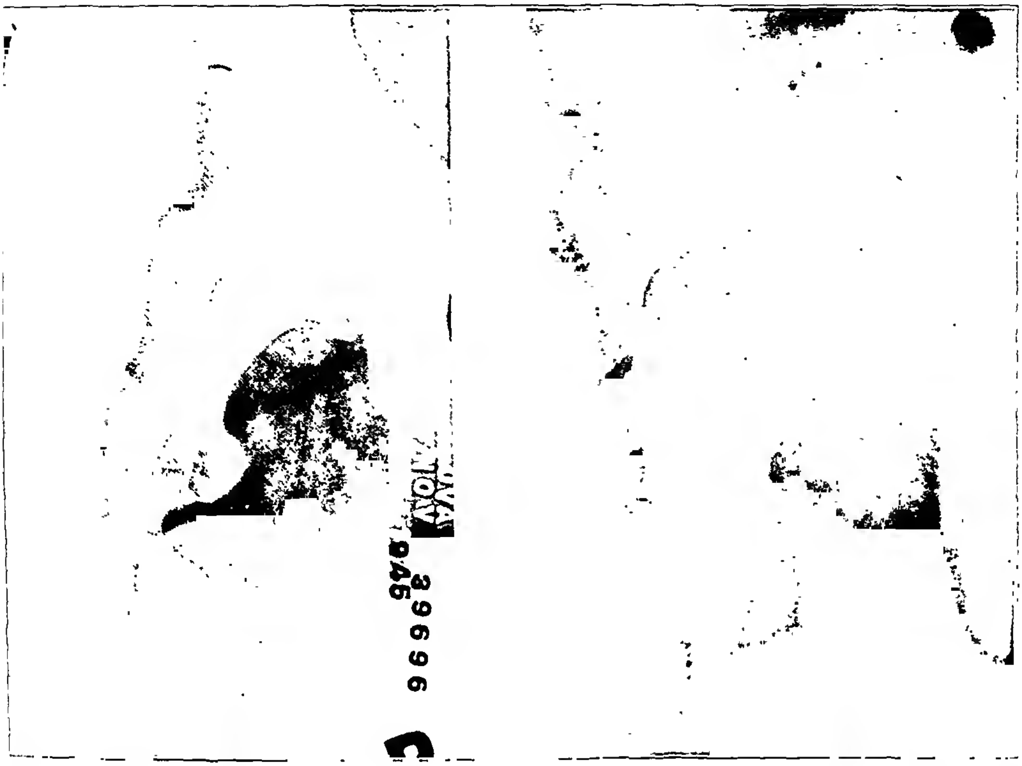


FIG. 1-A
Ununited fracture of right femur, seven months after injury.

FIG. 1-B

FIG. 1-C

Fig. 1-B: Cortical onlay graft and Moore plate in position, four and one-half months after operation.
Fig. 1-C: Femur is united and plate has been removed, seven months after operation.

posed by reflecting the periosteum above and below the wound area, where the bone was normal, and gradually freeing the ends of the fragments from the intervening scar tissue. Reflection of the periosteum was done as conservatively as possible. All scar tissue between the bone ends and usually the very sclerotic bone at the ends of the fragments were then removed. The medullary canal was opened by drilling, if this was considered necessary. The cortices of the fragments were then freshened with an osteotome, until flat enough to receive the graft. The cortical graft was cut from the subcutaneous surface of the tibia, and fixed to the fragments by Vitallium or stainless-steel screws. An overlap of 5 centimeters on each fragment in the arm, and 6.2 centimeters in the leg, was considered the minimum for safety; and more was allowed if possible. Cancellous bone from the upper end of the tibia was then inserted in the defect and around the graft. In the operations performed later in the series, cancellous bone from the ilium was used as well, if enough could not be obtained from the tibia to fill the gap completely. An attempt was made in all cases to have the graft bed as free from scar tissue as possible; in this way it was hoped that the vascularization of the graft would proceed more quickly.

In some situations this graft may be subjected to greater stress than it can reasonably be expected to withstand. In an intertrochanteric fracture or a fracture of the upper shaft of the femur, a spica cannot be molded accurately enough to control all movement at the fracture site; and absorption and fracture of the graft are apt to occur. In four such cases the graft was combined with a metal plate. In the intertrochanteric fractures, the Moore plate was used, with the cortical graft on the anterior surface of the femur. In the shaft, a Lane plate was applied anteriorly and the graft was placed laterally. In two cases, double onlay tibial grafts, one applied anteriorly and one laterally, were used instead of a graft and plate. The results have been equally satisfactory.

The cortical onlay graft has the advantage of great strength and firm internal fixation of the fragments. It must, however, be protected by plaster immobilization until the roentgenograms show that union is well advanced. The greatest strain on this rigid graft is at the fracture line or bone gap. If there is movement within the plaster, absorption and fracture of the graft are very apt to occur. This is particularly true in the ulna; in this bone a rotation strain at the site of the fracture is bound to occur, unless the hand portion of the plaster remains rigid and dry. This is the crux of after-treatment, but patients not under constant supervision are apt to return with the plaster below the wrist soft and moist, and some degree of pronation and supination possible. Two of the five cortical onlay grafts to the ulna failed for this reason.

In the femur, the use of the metal plate may prevent failure, by taking some of the strain from the graft (Figs. 1-B and 1-C).

The cortical inlay graft was used twenty-seven times in this series, in the following bones: metacarpals two, radius one, ulna five, tibia seventeen, medial malleolus one, and lateral malleolus one. The technique used was similar to that originally described by Albee, except that fixation, when used, was by screws of Vitallium or stainless steel rather than by dowelling. In the metacarpals and malleoli, because of the small size of the bones, fixation was secured by stainless-steel wire.

In the tibia, the fracture line was first cleared of all scar tissue, and the ends of the fragments were freshened. In cutting the grafts from the subcutaneous surfaces of both fragments, the electric saw was placed at such an angle that the graft was slightly wider on the periosteal than on the endosteal surface. The longer graft was then placed across the fracture line; if a defect had to be bridged, the shorter graft was cut up and packed into the gap. In most cases the graft across the fracture line was fixed to the fragments by Vitallium screws; in some, if the gap was small, the graft was left free, and a 1.3 centimeter section was removed from the fibula to allow approximation of the bone ends. In all cases, cancellous bone was taken from the upper end of the tibia and placed between the fragments (Figs. 2-A and 2-B).

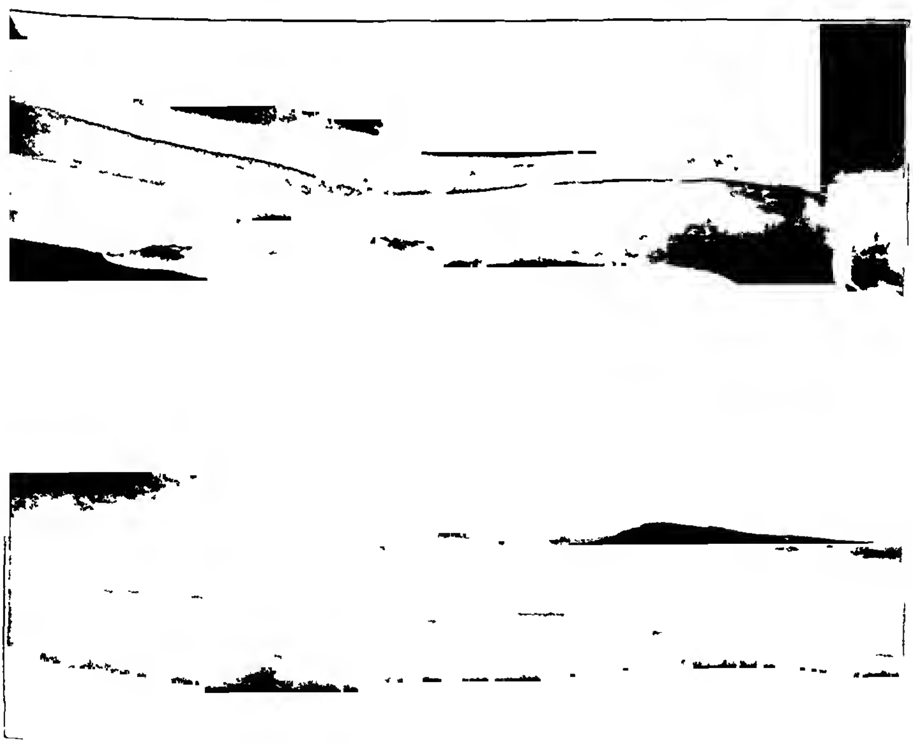


FIG. 2-A

Bone defect, 3.8 centimeters long, in right tibia, sixteen months after injury.

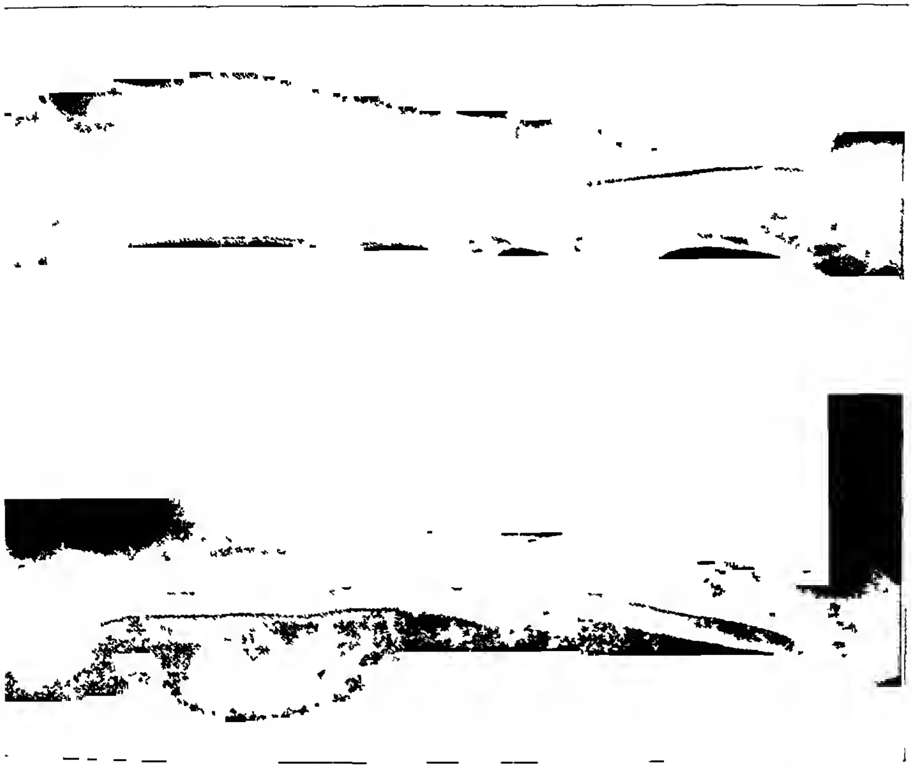


FIG. 2-B

Gap successfully bridged by sliding-graft technique, nine months after operation.

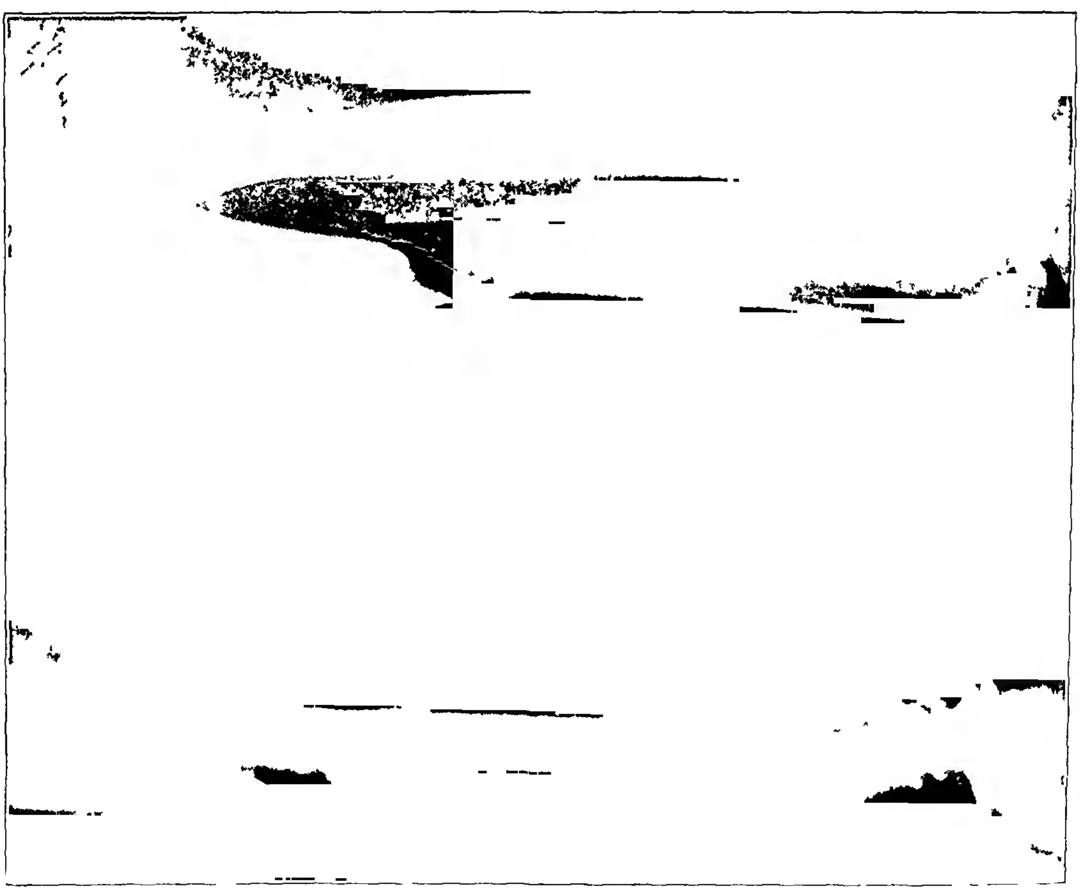


Fig. 3-A

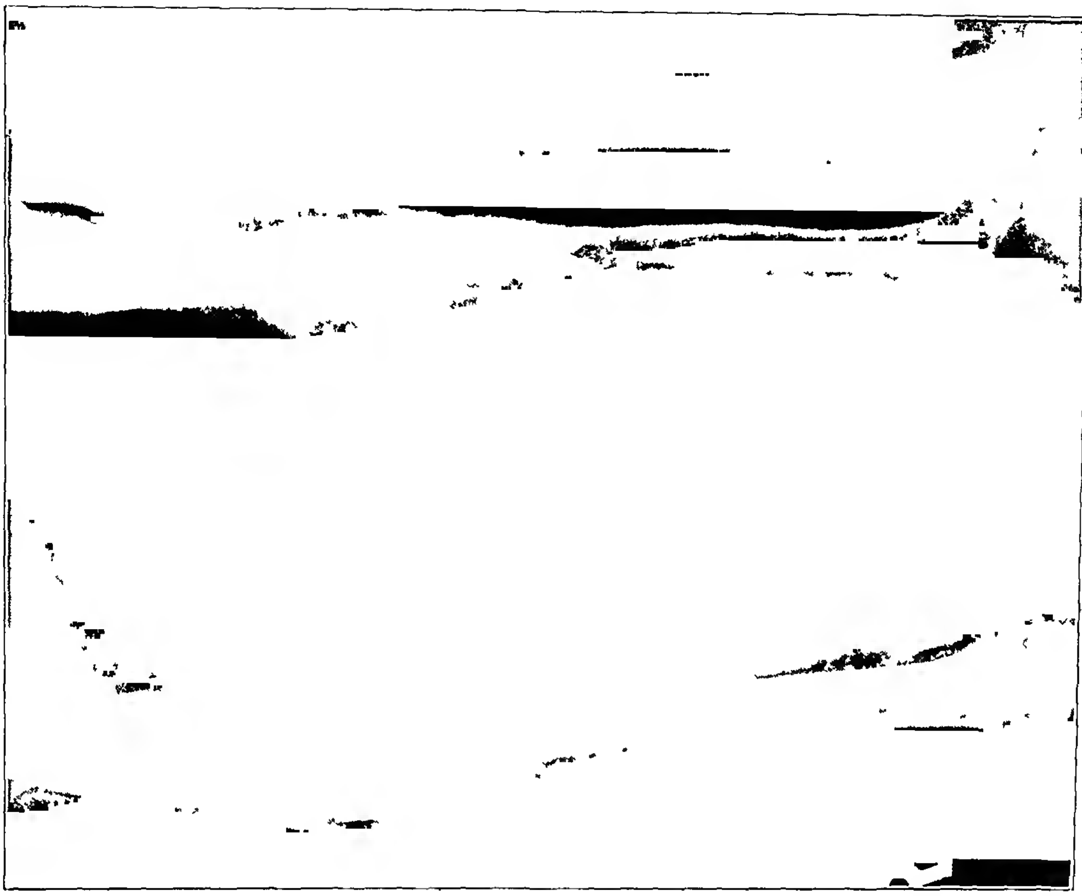


Fig. 3-B

Fig. 3-A: Ununited fracture of right ulna, the result of a gunshot wound.
Fig. 3-B: Seven months after bone graft, in which cancellous bone alone was used, the iliac bone has fused into one mass, and is becoming dense. Most of the excess bone will probably be absorbed.

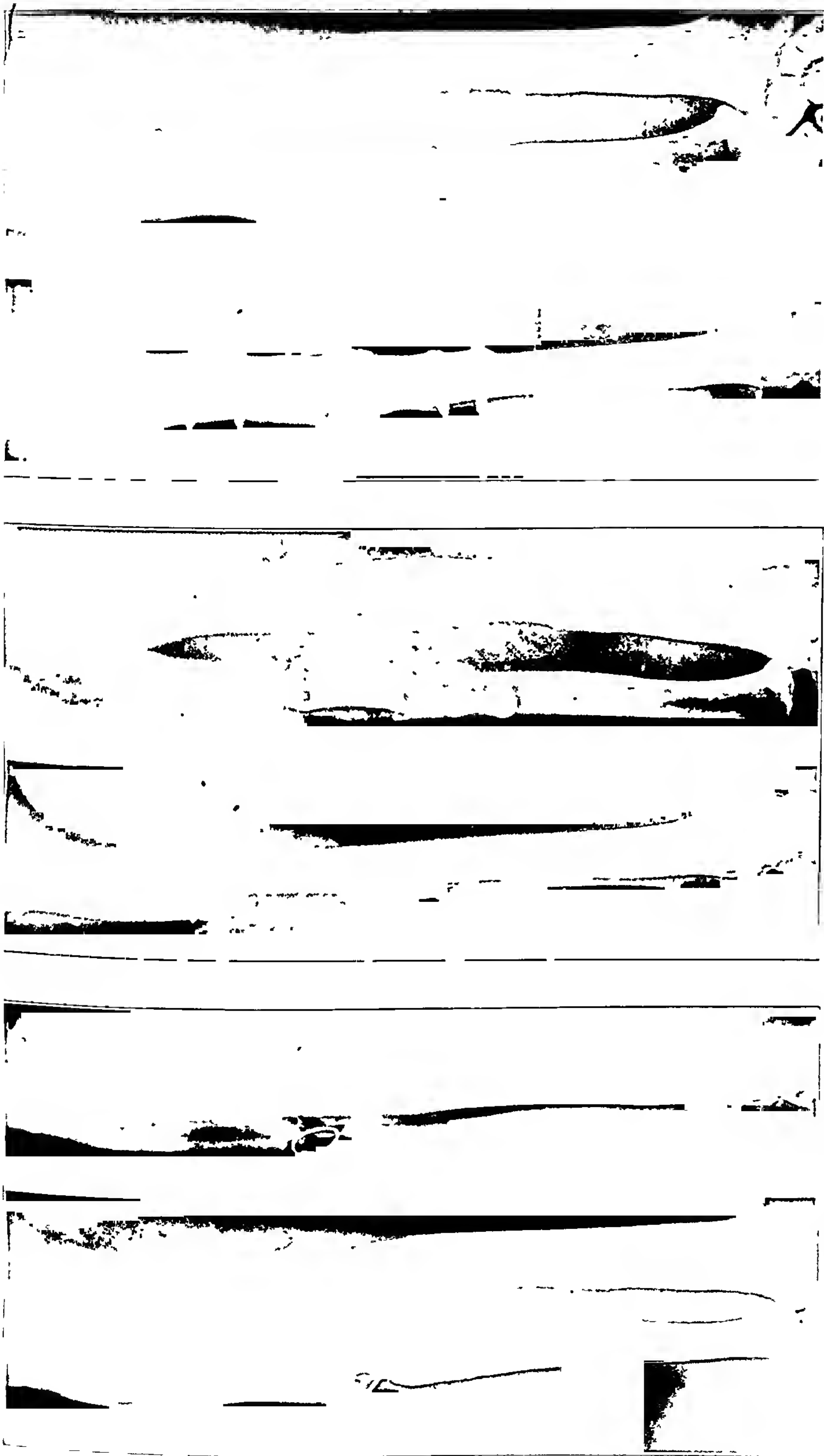


Fig. 4-A

Fig. 4-B

Fig. 4-C

Fig. 4-A: Ununited fracture of right ulna, ten months after an unsuccessful attempt had been made overseas to get union by wiring the fragments.
Fig. 4-B: Showing excessive cancellous bone used, two weeks after bone-grafting.
Fig. 4-C: Seven months after operation, ulna has united and excess bone has been absorbed.

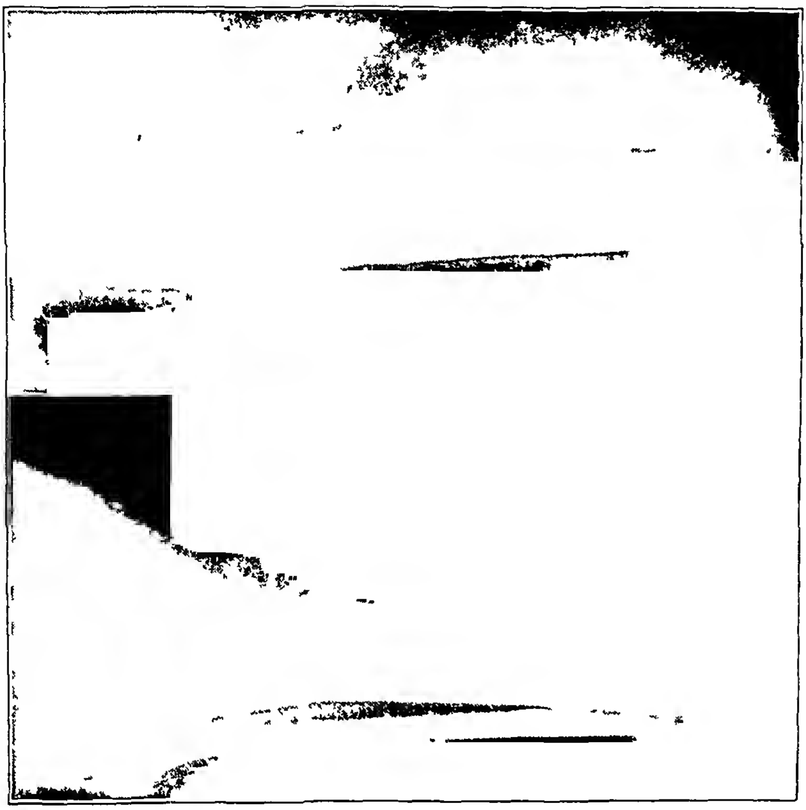
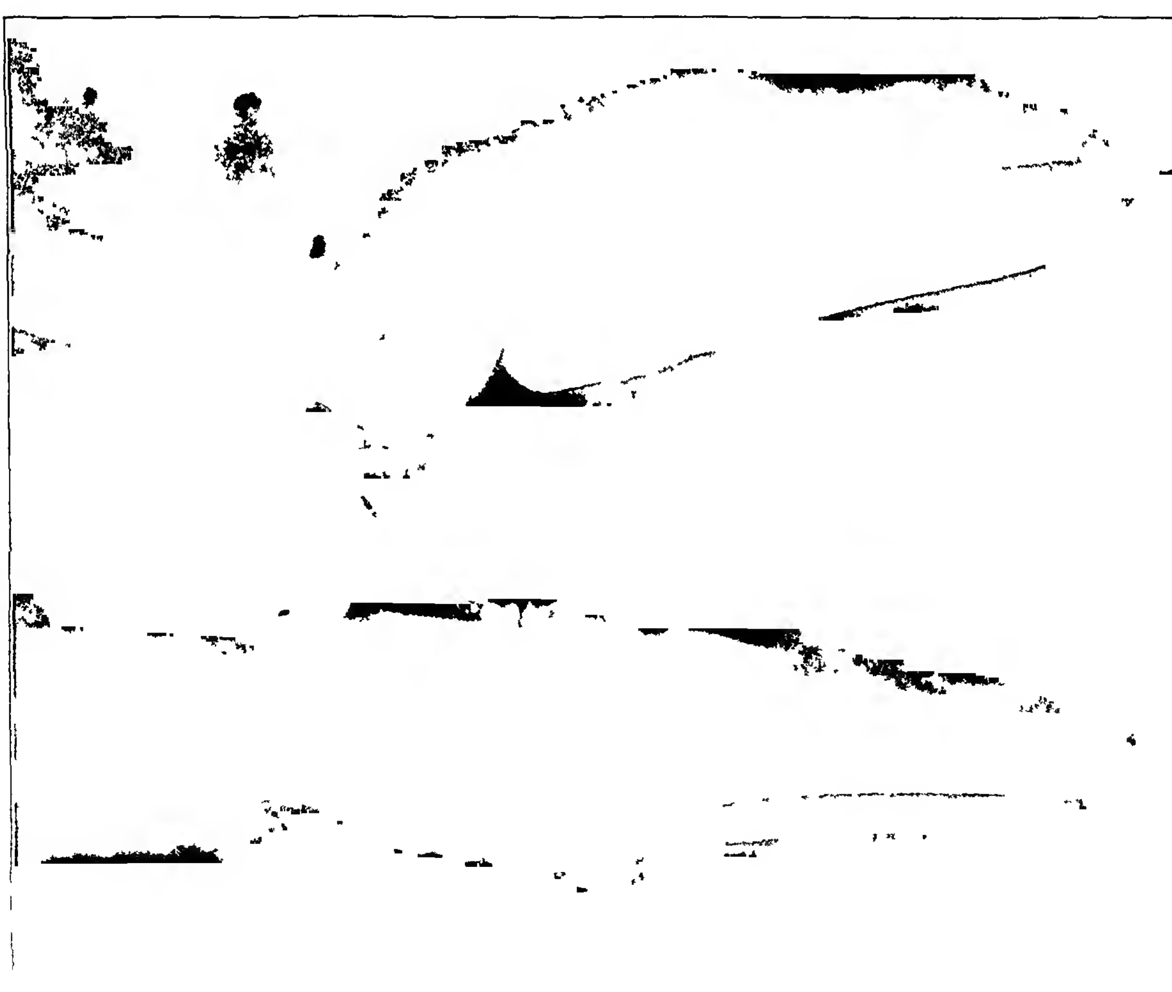


FIG. 5-B

Fig. 5-A: Infected cavity occupying head of tibia, with intermittent discharge since World War I and continuous discharge for a year before operation

Fig. 5-B: Cavity six months after operation. Wound had healed one month after operation Patient now wears prosthesis comfortably.



For the ulna, a cortical graft was taken from the tibia, inlaid on the lateral surface, and fixed by metal screws. Considerably more cancellous bone was obtained by this method than would have been the case if the sliding-graft technique had been used. In the metacarpals, a small tibial cortical graft was fitted snugly into a groove in both fragments and held by stainless-steel wire. For the malleoli, the graft was obtained from the upper fragment and fixed across the fracture line with stainless-steel wire.

The diamond inlay graft, described by Albee, was not used.

Cortical-chip grafts were used in only one case. In this, there was non-union of a fracture 5 centimeters from the lower end of the radius, with 1.3 centimeters of shortening. The lower end of the ulna was excised converted into chip grafts, and packed into the gap between the freshened fragment ends. Good union resulted from this procedure.

Numerous reports have appeared in the literature in the past few years on the use of cancellous-bone grafts. This type of graft can be used in several different ways, and is applicable in certain cases where cortical grafts would not be feasible. It can be used alone to fill gaps in the shafts of the long bones, or for the same purpose after fixation of the fragments with a metal plate. In cases in which there is a partial defect in the shaft, it is a very convenient method of increasing the strength of the bone. In a few cases, a solid block of iliac bone, with one cortex removed, has been used as an onlay graft, and fixed with Vitallium screws. In filling infected bone cavities, where saucerization would have been impossible, it has been most useful.

In all cases in which cancellous bone was used alone, the ilium has been the source of the bone. In approaching the ilium, it is advisable to have the skin incision along the lateral margin rather than over the top of the crest. If this is done, the incision is through fascia and periosteum alone; if it is higher, the muscles of the abdominal wall may be incised, with considerably more hemorrhage. It is advisable to use either the anterior or posterior third of the crest, as the middle third contains less cancellous bone.

When cancellous bone was used alone to fill gaps in the shafts of long bones, slices of the crest, about 0.3 centimeter thick, and the full width of the ilium, were cut with an osteotome. After removal of all scar tissue and the sclerosed bone ends, the slices were placed in the gap. Some were arranged to overlap slightly the ends of the fragments; smaller pieces filled the interspaces. The cortex was not removed from these slices. The grafts were held in place by soft-tissue suture only, and immobilization was by plaster. This method has been used twenty-two times,—fifteen times in the upper limb and seven in the lower limb (Figs. 3-A and 3-B).

In thirteen cases in which bone defects had to be bridged, a metal plate was used to fix the fragments, and cancellous bone was applied to fill the defect[3, 9]. Theoretically, this method would seem to be preferable, in that movement at the gap would be reduced to a minimum, and earlier removal of the plaster immobilization would be possible. This proved only partly true.

In some cases, only a partial defect of the shaft had to be grafted. In these, the bony wall of the defect was freshened, the medullary canal was opened above and below, and [illegible]ips of iliac bone were laid in the defect as free grafts. The interspaces were filled, as [illegible]ore, with small cancellous blocks, one-quarter inch by one-quarter inch by one-eighth [illegible]h in size. As much cancellous bone as possible was transplanted,—even more than [illegible]ugh to restore the original diameter of the shaft (Fig. 4-B). A good result seemed more [illegible]ain in cases in which this was done than in those in which less bone was used. No plaster [illegible]nobilization was necessary; but after the lower limb had been grafted, weight-bearing [illegible]s not allowed until union was well advanced.

This type of graft was used in nine cases,—three involving the upper limb and six involving the lower limb.

The use of cancellous bone to fill infected cavities was a matter of necessity rather than of choice in thirteen cases. These cavities were so situated that saucerization of them

was almost impossible. Some involved the whole or part of the upper end of the ti others were so situated in the shaft that, if saucerization had been done, only a narrow of bone would have been left to connect the fragments. One case had an infected tunn 1.3 centimeters in diameter, through the calcaneus; this had followed the use of a Stei mann pin for traction, in a military hospital. The tunnel had been curetted on two occa sions, but the discharge had persisted. Saucerization was obviously impracticable, bu filling the tunnel with cancellous bone was an easy procedure and gave an excellent resul

In recent years, several authors [8,12] have described the survival of cancellous-bon grafts in the presence of low-grade infection, and this has been borne out by our experienc If this method is attempted, there must be sufficient healthy skin available so that, whe the cavity has been filled, full-thickness skin can be closed over it without tension. If thi is not possible, the graft is apt to be completely or partially lost.

In each case the cavity was thoroughly curetted, so that all infected granulation tissu and scar tissue were removed, and bleeding bone was left to form the walls of the cavit Cancellous iliac bone, finely divided and with all cortex removed, was then placed in th cavity so as to fill it completely (Figs. 5-A and 5-B). In some cases this required a con siderable amount of the iliac crest, both anteriorly and posteriorly, but no harmful effect were noted after such extensive removal. If possible, muscle was used to cover the cavity but if this was not available, full-thickness skin was sutured over it. In the early cases, ureteral catheter was left in the bottom of the cavity, projecting through the wound, s that the graft could be irrigated regularly with penicillin. Later this was found to b unnecessary, and a penicillin-sulfathiazole powder was substituted. This mixture wa applied to the walls of the cavity after it had been curetted, as the cancellous bone wa being inserted.

In all cases, penicillin was administered for ten to fourteen days after the operation.

DISCUSSION OF RESULTS

For this report, any bone graft done before April 15, 1946, in which the limb wa still immobilized in plaster on December 1, 1946, was considered to be ununited, eve though roentgenograms taken at that time showed the graft to be uniting. In any cas classified as "united", solid bony union and good functional use of the limb were presen on December 1, 1946.

Seventeen of the patients had gaps of 1.3 centimeters or more, in the shaft of one o the long bones, which had to be bridged; four of these were 5 centimeters or more in length.

TABLE I

LOCATION OF BONE GRAFT IN NINETY-THREE SUCCESSFUL CASES

Location of Graft	No. of Cases in which the Graft United	No. of Operations
Metacarpals	4	4
Radius	8	9
Ulna	16	21
Humerus	13	14
Clavicle	3	3
Femur	16	17
Tibia	25	27
Calcaneus	3	3
Medial malleolus	4	4
Lateral malleolus	1	1
Totals	93	103

TABLE II

LOCATION OF TWELVE UNSUCCESSFUL BONE GRAFTS

Location of Graft	No. of Cases in which the Graft Did Not Unite	No. of Operations
Metacarpals	1	1
Radius	1	1
Ulna	2	5
Femur	3	5
Tibia	3	3
Calcaneus	2	4
Totals	12	19

A total of 122 operations were performed on 105 patients in the two years following April 15, 1944. Bony union was achieved in 93 cases, after 103 operations. The bones which were grafted in these successful cases are shown in Table I. Of the ninety-three successful cases, union was obtained in eighty-four by one operation and in eight by two operations; one ulna required three operations before the graft had united. Hence 80 per cent. of the initial 105 operations were successful.

Twelve cases are classified as having non-union, although in four the grafts are uniting, following a second operation. A total of nineteen operations were performed on these patients (Table II).

No conclusions should be drawn from the figures in Tables I and II, which represent all the different types of grafts used, including the cancellous grafts for infected cavities. The results indicate, however, that any patient who underwent a bone-graft operation during this period had an 80 per cent. chance of a successful result from the first operation, regardless of the type of graft used.

Of the patients in whom cortical onlay grafts were used, bony union developed in 85 per cent. after one or more operations. Of the initial operations, 79 per cent. were successful (Table III). This is 1 per cent. less than the average for the whole series. It is felt that the poor results obtained in the radius and ulna require explanation.

The unsuccessful graft to the radius was an attempt to bridge a 7.5 centimeter gap in a patient in whom the upper fragment was too short for fixation of the graft with metal screws. This fragment was split and the graft was laid between the halves. Union occurred at the lower end, but not at the upper, where fixation was poor. In the ulna, one unsuccessful case was a fracture of the upper third, with a dislocation of the head of the radius. The

TABLE III

RESULTS WITH CORTICAL ONLAY GRAFTS

Location of Graft	No. of Cases in which Grafting Was Done	Operations Performed	No. of Cases with Union
Radius	2	2	1
Ulna	4	5	2
Humerus	9	10	9
Clavicle	2	2	2
Femur	6	6	5
Femur with metal plate	4	4	4
Totals	27	29	23

TABLE IV

RESULTS WITH CORTICAL INLAY GRAFTS

Location of Graft	No. of Cases in which Grafting Was Done	Operations Performed	No. of Cases with Union
Metacarpals	2	2	1
Radius	1	1	1
Ulna	3	5	2
Tibia	17	17	16
Medial malleolus	1	1	1
Lateral malleolus	1	1	1
Totals	25	27	22

graft was not strong enough to prevent lateral angulation of the ulna, and broke. Th graft has been repeated, combined with a metal plate, and union is occurring. In the othe case, two successive cortical onlay grafts, bridging a 2.5 centimeter gap in the middle of the shaft of the ulna, became absorbed and fractured at the center of the defect. This was probably due to inefficient plaster immobilization. After both operations, the patient returned from leave able to pronate and supinate the hand freely, the plaster bar in the palm being soft and useless.

It is likely that, if the radius and ulna had been grafted in a greater number of cases, the results would have been comparable with those of the humerus and femur. There is no reason to believe that the ulna is a more difficult bone than the humerus in which to get union by this method.

The results obtained with the use of this graft in twenty-seven cases are very similar to those obtained by Henderson in 1923. In his series, however, the ulna gave the highest percentage of successful results.

The average time of immobilization of the upper limb was three and one-half months; in the lower limb it was four months.

This method of bone-grafting is regarded very favorably. Some authors feel that the dense graft takes an unduly long time to unite with the fragments. This opinion has not been confirmed by this series; and the greater strength in the shaft, when the graft has united, is definitely a point in its favor.

The cortical inlay graft (Table IV) produced bony union after one or more operations in 88 per cent. of the cases in which it was used. Of the initial operations, 81 per cent. w successful.

The inlay bone graft for the radius and ulna is not regarded as a good opera procedure. Because of the small diameter of the bones, only a narrow graft can be This makes for a weak graft across the fracture line and for relatively poor fixation fragments. In none of the cases involving the ulna, was the inlay graft successful t time used; and, when a second operation was attempted, about one third of the shaft unavailable for use. This method of grafting for the ulna has been abandoned.

The inlay bone graft gives excellent results when used for the tibia. In the one failure in seventeen cases, the patient had a complete sciatic-nerve lesion with disturbed circula tion, and roentgenograms showed no change after nine months. A Stokes-Gritti amputa tion was done. The average period of immobilization for the tibia was four months. The results indicate that it makes no appreciable difference whether the graft is fixed with metal screws or not, as union occurred in all cases, except the one mentioned. It is ap that this method of grafting the tibia can be depended upon to give consistent results.

TABLE V

RESULTS WITH CANCELLOUS BONE ALONE

Location of Graft	No. of Cases in which Grafting Was Done	Operations Performed	No. of Cases with Union
Metacarpals	3	3	3
Radius	4	4	4
Ulna	7	7	6
Humerus	1	1	1
Clavicle	1	1	1
Femur	4	4	3
Tibia	3	3	2
Totals	23	23	20

It is also an easy and apparently successful procedure to use for ununited fractures of the lateral malleolus. A cancellous bone block with a metal screw for fixation is a more satisfactory graft for the ununited medial malleolus, as this bone is usually too small and soft for a groove to be cut into it.

The cortical inlay graft for a metacarpal is a comparatively difficult operation. The diameter of the metacarpal shaft is too small to take an inlay graft large enough to be fixed with metal screws, and wire fixation is relatively unstable.

Cancellous bone alone was used to promote union in ununited fractures in fourteen cases, and to fill defects of 1.3 centimeters or more in the shafts of the long bones in nine cases. This method produced bony union, after one operation, in 87 per cent. of the cases in which it was used (Table V).

These results substantiate the claim of Luckey and Adams that cancellous bone alone can be relied upon to give union in a high proportion of cases. This method was used to treat three ununited fractures and four defects in the shaft of the ulna, and gave a higher percentage of union than was obtained with any other type of graft used for this bone.

The claim, however, that exposure of a greater amount of osteogenic bone produces more rapid union and earlier use of the limb was not verified. In the ulna, the average period of immobilization was seven and one-half months before roentgenograms showed union to be solid enough for the plaster to be removed. This was two and one-half months longer than the average for any other type of graft used for this bone. The additional immobilization is a handicap in the restoration of movement to the wrist and elbow joints. Union may occur more quickly; but, before the soft callus has become firm enough for

TABLE VI

RESULTS WITH CANCELLOUS BONE AND METAL PLATE

Location of Graft	No. of Cases in which Grafting Was Done	Operations Performed	No. of Cases with Union
Radius	2	2	1
Ulna	6	6	4
Humerus	1	1	1
Femur	3	3	2
[illegible]	1	1	1
To[illegible]	13	13	9

TABLE VII

RESULTS WITH CANCELLOUS BONE IN INFECTED BONE CAVITIES

Location of Graft	No. of Cases in which Grafting Was Done	Operations Performed	No. of Cases with Union and Wound Healing
Tibia	6	7	5
Femur	2	2	2
Calcaneus	4	6	2
Totals	12	15	9

unprotected use of the limb, more time has usually elapsed than if a cortical graft had been used.

In the metacarpals, this method proved easier and more effective than the cortical inlay graft.

Cancellous bone, combined with a metal plate (Table VI), produced union in 69 per cent. of the cases in which it was tried. The unsuccessful grafts were not repeated with this type of transplant. A defect in the shaft of over 1.3 centimeters in length was present in eight of these cases.

It is interesting to compare the results from the use of cancellous bone alone with those obtained when a metal plate was added. Although the number of grafts done by the latter method is too small to warrant definite conclusions, the addition of the plate would appear to have decreased the likelihood of union. It does, however, have one advantage. In cases in which the graft was successful, plaster immobilization was found to be necessary for an appreciably shorter time than when the plate was not used. The average period of immobilization for the ulna, when grafted by this method, was five months, as compared with seven and one-half months without the plate.

In three of the unsuccessful cases, the cancellous bone was used with a Lane plate, and failure was due to a gap of 0.3 centimeter, which persisted at the center of the plate. Above and below this gap, the cancellous bone fused into a solid mass, which united with the ends of the fragments. This did not happen in any of the cases in which a plate was not used, but whether or not the plate was the cause of the non-union is difficult to decide. It may be, as Luckey and Adams claim, that the plate takes the functional strains which normally pass through the bone, and thus interferes with complete fusion.

It may be concluded that, if cancellous bone alone is used, the chance of union is excellent. If the position of the fragments is difficult to control, a metal plate may be added without appreciably diminishing the expectation of union.

In nine cases, cancellous bone alone was used to strengthen the shafts of long bones in which there was an incomplete defect. This technique was successful in seven of the patients; the grafted bone fused into one mass and to the shaft. In one unsuccessful graft for a partial defect in the lower third of the shaft of the tibia, the cancellous bone had disappeared, as shown by roentgenograms taken several months later. In the other case, a cancellous bone block, approximately 8.8 centimeters long, was laid in an incomplete defect of the femur, but did not fuse with the shaft. Had this block been fixed with a few metal screws, or laid in as thin slices, it would probably have united.

Senior orthopaedic surgeons, in the interval between the two World Wars, found that cancellous bone would occasionally disappear completely from the grafted area. The explanation is obscure, but it would seem to occur particularly in cases in which the graft is not subjected to the normal compression or tension strains of the host bone.

The use of a block of cancellous bone as an onlay graft, with one or both cortices attached, is not recommended. If both cortices are retained, it is difficult to get a flat,

straight graft which is as satisfactory as a tibial onlay graft. If one cortex has been removed, the graft may easily fracture. Cancellous bone, with one cortex removed, was used twice on the ulna, with union in one case.

The use of cancellous bone in obliterating infected bone cavities (Table VII) was successful in 75 per cent. of the cases. Saucerization of the cavities was thought to be impracticable in all of these cases. In some, particularly those in which the calcaneus was involved, amputation seemed to be the only alternative.

Two operations on the tibia were unsuccessful. In both of these, the skin had been closed over the graft under considerable tension and the wounds had failed to heal. The procedure was repeated in one of these cases, and the skin was closed without tension by the rotation of a flap. This graft was successful. The other patient was transferred to a hospital closer to his home, with the cavity still discharging.

One patient, whose calcaneus was involved, had three cancellous grafts, and all failed because of inadequate soft-tissue closure. A below-the-knee amputation was done. The other failure in the calcaneus was the first infected cavity of this series to be treated by bone-grafting. A solid block of cancellous bone was used. This eventually had to be removed as a sequestrum. It is felt now that, had the block been finely divided, the graft might have succeeded.

In each case, the cavity had been discharging for months, and in some cases for years, before being filled with cancellous bone. As was to be expected, the discharge persisted through a small sinus in the wound for a short time after the operation. This diminished steadily in amount in the successful cases. The average healing time after operation was five weeks. Constitutional signs of infection arose in only one case, and these subsided without loss of the graft.

It would be rash to classify these cases as cured, but as yet there has been no recurrence of discharge in any of them. Some of the first patients so treated have been working for one and one-half years, and show no evidence of latent infection.

SUMMARY

Bone-grafting operations, for defects and non-union of the bones of the extremities, were performed on 105 patients at Deer Lodge Hospital between April 15, 1944, and April 15, 1946. Union has occurred in ninety-three cases.

Penicillin was used routinely after every operation, and no graft was lost or failed to unite because of primary wound infection.

In eighty-four cases, or 80 per cent., the first graft was successful.

The cortical onlay graft was used twenty-nine times for twenty-seven patients, and resulted in union in twenty-three, or 79 per cent. of the cases.

The cortical inlay graft was used twenty-seven times for twenty-five patients, and was successful in twenty-two, or 81 per cent.

Cancellous bone alone was used to fill gaps, or to promote union in ununited fractures, twenty-three times for twenty-three cases; union occurred in twenty, or 87 per cent. Combined with a metal plate, it was used thirteen times on thirteen patients, with union in nine, or 69 per cent. It was used nine times in incomplete defects of the shaft of the long bones, and fused with the shaft in seven, or 78 per cent. Cancellous bone alone was used to fill infected bone cavities, with discharging sinuses, in twelve cases. Wound healing occurred in nine cases.

CONCLUSIONS

For ununited fractures, or for short gaps in the shaft of the radius, ulna, humerus, and femur, the cortical onlay graft, fixed with Vitallium or stainless-steel screws, is the most efficient. Cancellous bone should be placed between the fragments and around the cortical graft. In the upper end of the shaft of the femur, it should be combined with a metal plate

or with a second onlay graft. In the ulna, if the size of the gap is 3.8 centimeters or more, or if the fragments are difficult to control, a Lane plate, used with the cortical onlay graft, may prevent absorption and fracture of the graft.

The sliding inlay cortical graft gives excellent results for ununited fractures, or defects of 5 centimeters or less in the shaft of the tibia.

Cancellous bone alone will bridge a bone defect, or promote union in ununited fractures in a high percentage of cases. However, before function can be allowed, longer immobilization must be expected than if a cortical graft has been used. Combined with a metal plate, union may be slightly less certain, but plaster immobilization is shorter. Its most practical use is in filling incomplete defects in the shafts of the long bones.

Infected bone cavities can be filled with cancellous bone and a high proportion of successful results can be anticipated, if full-thickness skin can be closed over the cavity and graft. This method may prove useful in the treatment of osteomyelitis of the tarsal bones.

NOTE: From April 15, 1944, to October 1, 1945, this work was carried out under the supervision of Lieutenant Colonel G. H. Ryan, R.C.A.M.C.

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CARPOMETACARPAL DISLOCATIONS

With Particular Reference to Simultaneous Dislocation of the Bases of the Fourth and Fifth Metacarpals

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Although carpometacarpal dislocations or subluxations of the thumb are not uncommon, those of the base of one or more of the four medial metacarpals are extremely rare. The infrequent occurrence of these dislocations, and the fact that we recently encountered two cases of simultaneous dislocation of the bases of the fourth and fifth metacarpals, have prompted a review of the literature and a tabulation of the reported cases of carpometacarpal dislocation, excluding those of the thumb.

Malgaigne, in 1855, stated that up to that time only three cases of dislocation of the carpometacarpal joints had been reported. The first of these cases was an isolated dislocation of the base of the third metacarpal, reported by Blandin in 1844. The second case, also an isolated dislocation of the base of the third metacarpal, was reported by Roux in 1848; and the third case was an isolated dislocation of the base of the second metacarpal, reported by Bourguet in 1853.

Vigouroux, in 1856, was the first to report a multiple carpometacarpal dislocation,—a dislocation of the bases of the second, third, fourth, and fifth metacarpals; and Rivington, in 1873, was the first to report a case of multiple dislocation of the bases of all five metacarpals.

Burk, in a review of the literature in 1901, found twelve cases of dislocation of the base of the fifth metacarpal; all were in association with other carpometacarpal dislocations.

Stimson, in 1910, stated that cases of isolated dislocation of the base of each one of the metacarpal bones except the fifth, had been reported, as well as combined dislocations of the bases of two or more metacarpals. McWhorter, who, in 1918, reported a case of isolated dislocation of the base of the fifth metacarpal, stated that he had been unable to find any record of a previous case. Many other authors have either omitted reference to these isolated dislocations of the fifth metacarpal or have commented on their non-occurrence or rarity.

In a rather careful review of the literature, a few additional cases of both isolated and multiple (simultaneous) carpometacarpal dislocations have been discovered, which have not been included in previous reviews on the subject. In addition, some inconsistencies have been found in the reporting or crediting of cases in some of these reviews. This is particularly true in articles concerning isolated dislocations of the fifth metacarpal.

Thirteen cases of isolated dislocation of the fifth metacarpal have been reported in the literature [16, 22, 31, 38, 41, 50, 57, 63, 76, 78], the first case having been recorded in 1879.

Among the other isolated dislocations, there have been seven cases of dislocation of the base of the second metacarpal [5, 11, 27, 30, 35, 37, 39]; the first case was reported in 1853. Three cases of dislocation of the base of the third metacarpal have been recorded [9, 65, 66]; the first case was reported in 1844. The first of the three cases of dislocation of the fourth metacarpal [1, 44, 61] was reported in 1868.

The most common of the multiple, simultaneous dislocations are those of the bases of the four medial metacarpals. Thirty-one cases, including the various types of dislocations of the four medial metacarpals, have been reported in the literature [8, 12, 14, 15, 18, 20, 24, 25, 28, 29, 32, 33, 34, 36, 42, 45, 51, 52, 55, 56, 58, 59, 68, 69, 71, 72, 74, 77, 79]; the first case

was reported in 1856. Simultaneous dislocations of the bases of all five metacarpals are more uncommon. Only five cases [40, 46, 60, 62, 75] of this type of dislocation have been found in the literature; the first case was reported in 1873.

Multiple, simultaneous dislocation of the bases of three metacarpals is even more uncommon. Only three cases [1, 26, 69] of dislocation of the bases of the second, third, and fourth metacarpals, and only one case [72] of dislocation of the bases of the third, fourth, and fifth metacarpals have been found in the literature.

Simultaneous dislocation of the bases of two metacarpals is also very uncommon. The first case of dislocation of the bases of the second and third metacarpals was reported in 1877. A total of ten cases can be found in the literature up to the present time [4, 6, 14, 19, 29, 53, 67]. Only three cases of dislocation of the bases of the third and fourth metacarpals [12, 51, 64], and only nine cases of dislocation of the bases of the fourth and fifth metacarpals [2, 3, 13, 47, 54, 70, 78] have been found in the literature. These two types of dislocations were first reported in the years 1895 and 1865, respectively.

Of the various types of multiple, simultaneous dislocations, this paper is particularly concerned with those of the bases of the fourth and fifth metacarpals. Eight of the nine cases of this type of dislocation were found in the foreign literature. The single case found in the American literature is the one reported by Bunnell in 1944. To this number we wish to add two cases, which will bring the total number of cases of this type of multiple, simultaneous dislocation to eleven.

CASE REPORTS

CASE 1. A Coast Guardsman, twenty-three years old, was admitted to the Hospital on July 18, 1945, complaining of pain and swelling of the right hand. He stated that the present condition of his hand was the result of an injury which had occurred about three and one-half months previously (April 2, 1945) when he had struck his right hand against a wall while engaged in a fist fight. The patient, however, had continued to work during the interval, despite the pain and swelling of the hand.

Examination showed a prominence and tenderness over the dorsum of the right hand, which was lo-

FIG. 1-A

FIG. 1-B

Fig. 1-A: Case 1. Roentgenogram showing dorsal dislocation of the bases of the fourth and fifth metacarpals.
Fig. 1-B: Roentgenogram following open reduction of dislocation and external skeletal fixation by means of Kirschner wires.

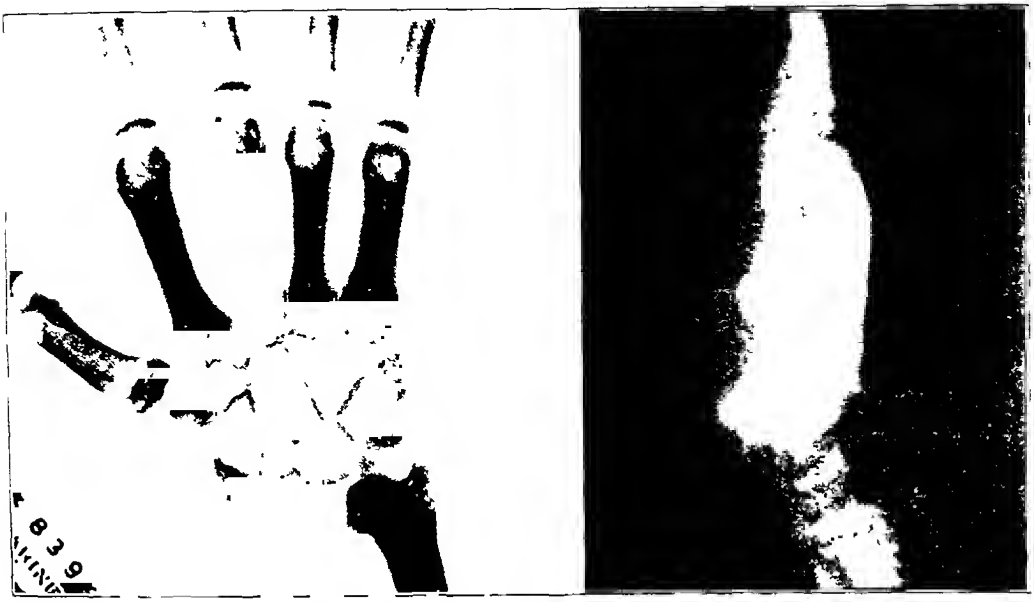

Fig. 1-C

Roentgenograms six weeks after open reduction, showing complete anatomical reposition of the carpometacarpal articulations.

:alized fairly well over the proximal ends of the fourth and fifth metacarpals. A roentgenogram revealed a lorsal subluxation of the bases of the fourth and fifth metacarpals (Fig. 1-A).

Closed reduction was unsuccessful, and, therefore, an open reduction was done under pentothal-oxygen anaesthesia. In order to maintain the reduction, it was necessary to use external skeletal fixation by means of Kirschner wires, inserted transversely through the proximal and distal ends of the affected fourth and fifth metacarpals and the adjacent third metacarpal (Fig. 1-B). With the hand in a cock-up position, light, molded plaster splints, incorporating the ends of the protruding Kirschner wires, were then applied.

At the end of three weeks, the Kirschner wires were removed, but the molded-plaster fixation was continued for a full five weeks from the time of the open reduction. Following this, physical therapy, including whirlpool-bath treatments, was instituted. The result, both anatomically and functionally, was excellent (Fig. 1-C).

Case 2. A merchant seaman, thirty-one years old, was admitted to the Hospital in an intoxicated state on August 14, 1945. The patient had been celebrating the approach of V-J Day and had injured his right hand, but he did not remember any of the details of the accident. His chief complaints were of pain and swelling of the right hand.

Examination showed swelling and a "dinner-fork" deformity of the ulnar portion of the hand. There was limitation of both flexion of the fingers and grasping power of the hand. The roentgenograms showed a posterior subluxation of the bases of both the fourth and fifth metacarpals (Fig. 2-A).

Under pentothal-oxygen anaesthesia, the dislocation was easily reduced by traction on the extended fingers and maintenance of the wrist in dorsiflexion. Following this procedure, immobilization, by means of molded plaster splints with the hand in a cock-up position, was continued for four weeks. Convalescence was aided by physical therapy and increasingly active use of the hand. The result was excellent (Fig. 2-B).

ANATOMY

The carpometacarpal joints at the bases of the second, third, fourth, and fifth metacarpals are all arthrodial diarthroses, or modified, compound saddle joints with an articular cavity within the capsule of each joint and a movement which is gliding in character. The opposed articular surfaces present alternate elevations and depressions, which form a series of interlocking joints. The articular capsule and the dorsal, volar, and interosseous ligaments unite the articular surfaces. "The articular cavity is a continuation of that of the intercarpal joints; occasionally there is a separate space between the hamate and fourth and fifth metacarpal bones, whereas that between the fourth and capitate is continuous with the common joint." [49]

The movements found at these joints, although slight, serve to increase the effect of those of the transverse carpal and wrist joints. The joint between the fifth metacarpal and the hamate bone somewhat approaches the first carpometacarpal joint in shape and

FIG. 2-A

Case 2. Roentgenograms showing dorsal dislocation of the bases of the fourth and fifth metacarpals.

FIG. 2-B

Roentgenograms following closed reduction, showing complete anatomical reposition of the carpometacarpal articulations.

mobility. It has, however, a greater range of flexion and extension, although its side-to-side movement is nearly as limited as that of the other three medial metacarpal bones. The process of the hamate bone limits flexion of the fifth metacarpal. Motion toward the ulnar side is checked by the strong palmar band which unites the base of the fifth metacarpal to the base of the third metacarpal, and by the strong transverse metacarpal ligament at the heads of the bones. The mobility of the second, third, and fourth metacarpal bones is very limited, and consists almost entirely of a slight gliding upon the carpal bones. Mobility of the third and fourth metacarpal bones is extremely slight, because there is no long carpal flexor directly attached to either. Owing to the close connection of the bases of the metacarpal bones, the radial and ulnar flexors and extensors of the carpus act on all of the metacarpals by their pull on the particular bones into which they are inserted.

Abduction, or movement toward the radial side at these joints, is prevented by the impaction of the second metacarpal bone against the greater multangular. A small amount of adduction is permitted at these joints and is favored by the slope of the hamate and the fifth metacarpal. There is also a slight gliding motion between the fourth and fifth metacarpals, when the concavity presented by the palm is deepened to form the so-called "cup of Diogenes".

MECHANISM OF INJURY

No one type of injury produces dislocation of the proximal end of any one or all of the four medial metacarpals on the distal row of carpals. Direct violence, such as is received in a fall or from a blow, is, perhaps, the most frequent mode of injury. However, in some instances, indirect injuries have been known to cause these dislocations. It is difficult to explain the exact mechanism of these injuries; and, therefore, one can only speculate as to the mechanical forces necessary to produce these dislocations.

In both of our patients we observed that, following reduction of the dorsally dislocated bases of the fourth and fifth metacarpals, there was a recurrence of the dislocations upon palmar flexion of the wrist, whereas the reduction was maintained by dorsiflexion. It is believed, therefore, that a force applied to the dorsum of the hand while the wrist is in a position of palmar flexion is the most likely cause of a dorsal dislocation of the base of one or more of the four medial metacarpals. The reverse of this mechanical force would most likely result in a volar dislocation.

Burk, when attempting to produce carpometacarpal dislocations on cadavera, usually obtained fractures. In his experiments, he found it necessary to cut the anterior and posterior ligaments in order to obtain a dislocation. Shorbe repeated Burk's experiments with similar results. Attempts to produce these dislocations on fresh specimens with the carpus fixed were unsuccessful, unless the anterior and posterior ligaments were divided. A dislocation could then be produced by unlocking the bones with flexion and applying pressure to the bases of the metacarpals.

Hammann noted that the carpometacarpal joints have strong junctions and ligaments, and he stated that luxation of these joints could only occur as a result of special or severe injuries.

Mittler, in referring to the experimental research and cadaver studies by Burk, Biancheri, and Romani, stated that the mechanism which produced carpometacarpal dislocations was usually that of a direct force applied to the bases of the metacarpals, and that the resulting volar or dorsal dislocation was determined by the direction of the force. According to Olper, a force applied to the heads of the metacarpals could cause either a luxation of the bases or a compression of the radial and ulnar aspects, which would augment the concavity or the convexity of the hand, and finally cause a laceration of the ligaments and a dislocation of the affected joints, as experimentally demonstrated by Burk. The relatively frequent occurrence of laceration of the dorsal carpometacarpal ligaments in forceful flexion of the hand has also been noted by Biancheri and others.

CLINICAL FEATURES

The usual symptoms of dislocation are pain, swelling, and impairment of the function of the hand. Objectively, there is marked swelling and deformity. The deformity is variable as to site, depending upon whether the displacement is volar, dorsal, lateral, or mixed (divergent). With the more frequent dorsal dislocation, there is a characteristic "dinner-fork" deformity with the depression in the palm. In a volar dislocation, the palm is markedly thickened, and, different from the dorsal dislocation, there may be present a "spade type" of deformity, analagous to the type of deformity seen in the reversed Colles's fracture. Motion of the joints of the affected finger or fingers and the grasping power of the hand are limited.

DIAGNOSIS

As with most wrist injuries, the diagnosis is based chiefly upon the roentgenograms and their interpretation by one who has a thorough knowledge of the anatomy of the carpus.

TREATMENT

In early cases of carpometacarpal dislocations, reduction by closed methods is usually accomplished without difficulty. In attempting closed reduction, it is essential to maintain manual traction on the corresponding fingers of the metacarpal for a sufficient period before applying local pressure or beginning any other necessary manipulation. Canavero and others also stress the importance of applying traction to the fingers and countertraction to the wrist, accompanied by pressure and counterpressure over the palmar and dorsal aspects of the hand at the site of the dislocation.

In late cases, reduction may be very difficult, and sometimes is only possible by an open operation. In regard to the difficulties of late reduction, Shorbe states that unreduced carpometacarpal dislocations do not always produce serious disabilities. Burmeister, and Roberts and Holland, also report good function in some cases in which satisfactory reduction was not obtained. Bunnell, however, states that "reduction is necessary to restore muscle balance and proper mechanics in the hand". Serious consideration should, therefore, be given to old unreduced dislocations before an attempt is made at reduction, particularly open reduction, as the result may be only an improvement in the appearance of the hand, but no actual improvement in its function. This would be particularly true for those patients in whom full restoration of function of the hand is not too important.

Following reduction of a carpometacarpal dislocation, immobilization with molded plaster-of-Paris splints should be maintained for from two to four weeks, depending upon the ease both of reduction and of maintenance of the reposition. In old unreduced dislocations, particularly when open operation is required, external skeletal fixation with Kirschner wires may be necessary to maintain the reduction. In such cases, the wires are inserted transversely through the bases and heads of the dislocated and the adjacent, normal metacarpals. The hand is then immobilized with a light, molded plaster-of-Paris dressing, in which the projecting ends of the wires, capped with corks, are incorporated. Following the period of immobilization, recovery is facilitated by physical therapy.

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PRIMARY CLOSURE OF COMPOUND-FRACTURE WOUNDS

With Immediate Internal Fixation, Immediate Skin Graft, and Compression Dressings *

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A review of fifty consecutive cases of compound fracture was presented to this Association in 1942 by Davis and Fortune. The treatment consisted in immediate débridement, metallic internal fixation, skin-grafting, and compression dressings. The previous practice of leaving compound-fracture wounds open, and thus treating deep tissues in the same general manner as superficial tissues, had seemed illogical to the writer; however, routine primary closure had been considered to be precluded by the current hazards of local and general sepsis. Four physicochemical factors were pointed out as being normal for the skin, but devitalizing for deeper tissues,—whether bone, tendon, muscle, joint structures, or other soft parts. The surgical principles of compression and exclusion of air from the deeper tissues are supported by evidence in medical literature, dating back as far as the seventeenth century and including significant contributions from Gamgee, Ollier, Larrey, Arey, Blair, Orr, and Koch; the orientation of these principles has varied, however, as surgery has passed through successive stages of pre-antiseptic, antiseptic, aseptic, and bacteriostatic techniques. The innovation of immediate closure was designed to restore the normal environmental state of the deeper cells; their innate defense mechanisms were considered to be of greater therapeutic value than the action of a bactericidal agent. Results in the fifty reported cases were good enough to warrant continuation of this type of treatment.

The present report is based upon a series of 150 consecutive cases of compound fracture **, observed during the eleven-year period from 1936 through 1946. During the first five years, when neither sulfonamides nor penicillin were available, twenty-eight cases were treated. In the next four years, eighty-three cases were treated with sulfonamides. In the final two years, thirty-nine cases were treated parenterally with penicillin; in addition, in these cases a sulfonamide was dusted into the wound. During the last five years a blood bank has facilitated the generous use of transfusions, and a high-protein diet has been prescribed.

Except for modifications attending the advent of the newer bacteriostatic agents, the blood bank, and the high-protein diet, the program of treatment described in 1942 has undergone no important change. Greater experience, however, has taught the value of a *more radical excision* of questionable skin. With the adoption of this policy, it has been possible to reduce the incidence of sloughing of the wound edges and subsequent infection. Improved techniques in the transfer of split grafts, together with the use of the Padgett dermatome, have facilitated the grafting of large denuded areas.

In the 150 cases of this series, there were fifty-five compound fractures of the tibia or of both bones of the leg, and fifty-two of the fingers or hand. The humerus was fractured in eleven instances, one or both bones of the forearm in fourteen, the femur in two, and other bones in five. Twenty-five of the fractures involved joints: among these were included twelve ankles, five elbows, three knees, and two wrists. There were four deaths; of these two resulted from pneumonia, one from embolism, and one from gas

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**These cases were treated on the Services of C. W. Fortune, M.D., Michael Skovron, M.D., and the writer, at the Hamot Hospital, Erie, Pennsylvania.

gangrene. One above-the-knee amputation was necessary because of the development of gas gangrene.

One hundred and thirty-one, or 87 per cent. of the wounds, healed by first intention. Sloughing of the wound edges occurred in thirteen cases, some of which became infected. Drainage persisted in one tibia for two months, but the bone united in six months. One plated tibia showed healing of the soft tissues by first intention in two weeks; drainage after three weeks; the development of a diffuse osteitis, requiring removal of the plate and sequestrectomy; and finally non-union. This is now being treated by bone-grafting for the second time, a first graft having been unsuccessful. This case is an outspoken failure and defies explanation. One plated tibia exhibited a sloughed skin flap, about three by six centimeters in area, located directly over the plate. The plate was removed after union occurred, and the patient returned to work six months after the injury. Chronic osteomyelitis developed in another plated tibia and the case passed out of our hands; the outcome is unknown. One fracture of both bones of the forearm showed drainage when first dressed, two weeks after the injury, and a sequestrectomy was required; in nine months the patient had regained complete function of the forearm.

Twenty-nine tibiae were fixed by plates or by Vitallium screws alone, immediately after admission. Eight others were plated after the soft tissues had healed by first intention. Three cases required bone grafts. In four, union was delayed or otherwise faulty. A total of twelve cases had skin defects, requiring large grafts. This is exclusive of fingers, in which defects are frequently closed with full-thickness grafts. Farmer and Mathewson have shown that extensive avulsed skin flaps may be used to cover defects.

About mid-way in the series it became apparent that the most frequent cause of failure of healing by first intention was the attempt to preserve questionable skin. It is now realized that, notwithstanding careful technique applied to the deep tissues, questionable skin edges jeopardize the entire result long after the deep tissues have healed. One of three methods is therefore used, its selection depending upon the demands of the individual case: (1) When adequacy of the circulation in a skin flap is doubtful, the tourniquet is removed; if vitality of the flap is not demonstrated, the flap is resected. (2) When longitudinal flaps can be mobilized and drawn together to cover the denuded area, this is done in preference to placing a split graft over the defect; and the defect caused by the shifting is covered secondarily by a split graft. (3) Frequently it is possible to bring the wound edges together without tension by undermining them and using relaxation sutures of stainless-steel wire. In no case has there been a noticeable reaction to the wire.

It is sometimes impossible and frequently inadvisable to do combined immediate treatment of shock, débridement, internal fixation and closure. For this reason several different approaches, depending upon the immediate requirements of the individual patients, are outlined in the case reports.

The first case to be described illustrates the severe type of injury in which immediate operation plus immediate shock treatment go hand in hand.

CASE REPORTS

Case 1 (M.A.). On July 1, 1942, the patient was underneath a magnet, carrying a ton of steel scrap, which accidentally became demagnetized. The patient sustained an amputation just below the right knee, a deep lacerated wound of the right forearm with avulsion of most of the extensor muscles, and a compound fracture of the left femur. Emergency wire tourniquets were applied to the three injured extremities, and the patient arrived at the Hospital thirty minutes after the accident. The treatment included an immediate Callander amputation of the right thigh; immediate débridement of the right forearm wound, with primary closure of the skin and compression dressings; and immediate débridement of the compound fracture of the left femur, with the application of Kirschner wire traction and a Thomas splint. The patient's hemoglobin was 57 per cent. One thousand cubic centimeters of plasma was given during the initial surgery; approximately 4,000 cubic centimeters of blood, plasma, and glucose solution, and a total of six cubic centimeters of adrenal cortex were given during the first two days. The level of sulfadiazine in the blood was maintained at about eight milligrams per 100 cubic centimeters for two weeks.

Two months later there was no evidence of union of the left femur, and a sliding bone graft was applied. Four months later a typical transplantation of flexor tendons to the remains of the extensors in the right forearm was carried out. Nine months after the accident the patient was discharged home with an artificial limb. Seventeen months following the accident, he returned to work. He has since remained uninterruptedly at his job of operating a machine tool.

Immediate skin coverage of the right forearm, after careful débridement, paved the way for the reconstruction and future function of the right hand. The three wounds were clean and dry at the first dressing, two weeks after the injury.

The second case demonstrates the value of immediate, thorough débridement plus immediate skin coverage.

Fig. 1-A
Massive avulsion of extensor muscles and skin of forearm.

Fig. 1-B
First dressing, two weeks after primary suture and split-thickness skin graft.

Case 2 (L. K.). On June 16, 1943, the patient's right forearm was caught between the roller and the belt of a conveyer system. Most of the extensor muscles were avulsed, and the skin defect measured about four by seven inches (ten to eighteen centimeters) (Fig. 1-A). About four inches of the ulna and radius were laid bare, and a strip of periosteum, one-half inch wide and four inches long, was torn from the radius. The remains of the extensor muscles were debrided, and the skin edges were resected in the usual manner; the tourniquet was removed to determine the viability of remaining deep tissues and skin, and was then reapplied. The long extensor and the abductors of the thumb were uninjured. The middle of the wound was sutured; the rest of the defect was covered by a split-thickness skin graft, three by eight inches in size, taken from the left thigh. Sulfanilamide crystals were dusted into the wound, and a cast was applied over compression dressings of sterile gauze fluffs and sea sponges. The patient received 500 cubic centimeters of plasma during operation and 1,000 cubic centimeters of glucose afterward: his blood sulfadiazine level was maintained at between five and ten milligrams per 100 cubic centimeters for a week.

At the first dressing, two weeks after injury, the wound was clean and dry (Fig. 1-B). The hospitalization period was seventeen days. Three months later a typical flexor-tendon transplant for drop wrist was performed. The patient began light work five months after injury; two months later he returned to his former occupation of running a coal-loading machine.

In both Case 1 and Case 2 the injuries were caused by machine-shop accidents. It has been the author's experience that these wounds are not particularly dangerous as regards infection, although they may be greatly soiled with grease and foreign bodies.

The next case illustrates a combination of immediate treatment of shock, immediate wound closure, and delayed internal fixation.

Case 3 (J. S.). In a street accident a man, fifty-six years old, was knocked over by an automobile. He sustained compound fractures of the right tibia and fibula: a ragged laceration of the middle third of the right leg, exposing bone; a right Monteggia fracture with the ulna broken at two levels, a dislocation of the right shoulder; a fracture of the right innominate bone and the sacrum; a fracture of the right transverse process of the fourth lumbar vertebra; and fractures of fifth to tenth ribs, with depression of the chest and subcutaneous emphysema.

Immediate treatment consisted in the administration of plasma; débridement and closure of the compound leg wound, which measured three by five inches (eight to thirteen centimeters); casting alone for the fractures; reduction of the shoulder dislocation; and compression dressings for the forearm and leg. During the first two days the patient's condition was precarious; he received 50,000 units of penicillin every three hours, one unit of blood, and about 4,000 cubic centimeters of 5 per cent. glucose in saline. After two weeks, devoted chiefly to treatment of the chest injury, an attempt was made to treat the fractured ulna with an intramedullary Kirschner wire; this was unsuccessful because of an old fracture of the ulna. One week later, a double Vitallium plating of the tibia was done; and five weeks later a bone graft of the ulna was performed and the radial head was reduced and retained by means of a fascial strap, according to the method of Speed and Boyd. The arm and leg casts were removed five months after the accident, and physiotherapy was then carried out for two months. The patient returned to work as a foreman, six and one-half months after the injury.

All fracture treatment was delayed by the precarious condition of the patient on admission. Immediate treatment of shock was imperative. Locally, the most important initial objective was healing of the compound wound by first intention; this was attained two weeks after the débridement, primary suture, and application of compression dressings.

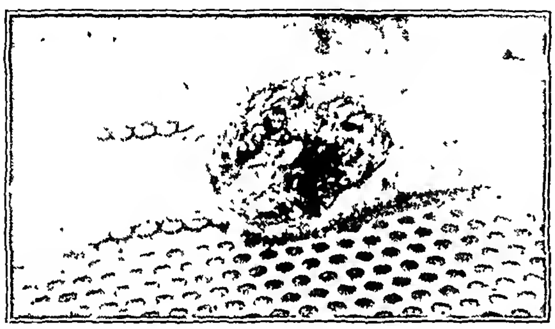

Fig. 2-A

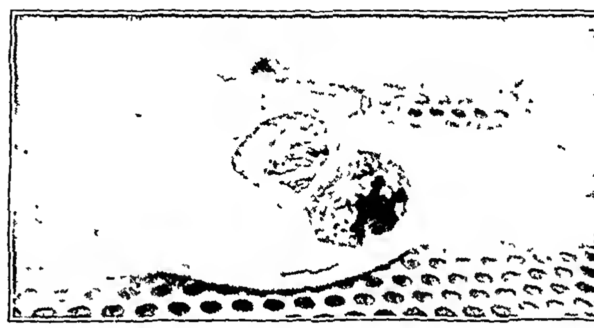

Fig. 2-B

Fig. 2-C

Appearance of gunshot wound on admission, six hours after accident.

FIG. 2-D

Appearance immediately after operation, following removal of accessible bone and lead fragments, and partial internal fixation.

The fourth case illustrates a distinctly borderline type, in which survival of an extremity seems extremely questionable without primary suture, immediate skin-grafting, and compression dressing; and in which survival of the individual may be jeopardized if immediate amputation is not carried out.

FIG. 2-E

Appearance of wound at time of first dressing, two weeks after débridement. An immediate split-thickness skin graft had been applied.

CASE 4 (J. M.). In December 1942, the patient's left forearm was wounded by a soft-nosed bullet fired from a deer rifle; after penetrating the flexor surface, the bullet exploded. The appearance of the wound on admission of the patient, six hours after the injury, is shown in Figures 2-A, 2-B, and 2-C. The hand was warm, with scattered areas of intact sensation. Two units of plasma were given, and immediate débridement was carried out. The muscles had been converted to a pulp: they were spooned out, together with fragments of lead and bone, down to sound tissue. The dorsal defect was sutured flap to flap; the medial defect was covered with a split graft, four by five inches in size, taken from the inside of the thigh: and the fragments of the ulna and radius were brought into approximate alignment, one being fixed with a screw and the other with a mattressed wire suture. A compression dressing, consisting of gauze fluffs and sea sponges, was applied, together with a plaster splint. All three attending orthopaedic surgeons took part in the operation.

The status of the wound at its first dressing, two weeks after the injury, is shown in Figures 2-D and 2-E. The level of sulfadiazine in the blood was maintained at five to eight milligrams per 100 cubic centimeters

and several transfusions were given. Three weeks later a hemorrhage from the wound edge was controll by compression dressings; on the following day, profuse bleeding necessitated ligature of the dorsal intero seous artery; two weeks later another hemorrhage required tying of bleeding points. During this perio

Fig. 3-A
Roentgenogram shows shattering fracture of frontal and nasal bones.

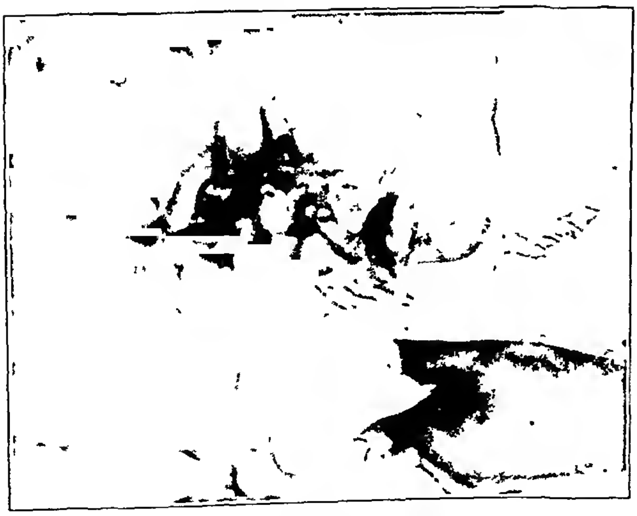

Fig. 3-B

Fig. 3-C

Fig. 3-B: Appearance at admission, after head-on automobile accident, with considerable ooze of cerebrospinal fluid and brain. The patient is unconscious. Immediate débridement and primary closure were carried out.

Fig. 3-C: Shows appearance at time of first dressing and stitch removal, two weeks after the accident.

several transfusions were given. The patient was discharged from the Hospital, with a draining sinus, on February 29, 1944, two and one-half months after the accident. A pedicle skin graft was done two and one-half years after the injury. The radius united solidly without a bone graft; only fibrous union developed in the ulna. The fingers are contracted, but retain patches of sensation in the distribution of all three nerves.

What the results in ten such cases would be is indeed problematic. The dilemma posed by such a case is the choice between sacrifice of the hand and risk of the individual's life. The availability of penicillin and whole blood persuaded us to attempt salvage of the hand in view of the realization that any kind of hand, even if nothing more than a paper weight, is more satisfactory than any kind of prosthesis. If the hand has sensation and if, after primary union or reconstructive bone surgery, it can be moved about by satisfactory supporting structures, the risk to the individual seems justified. In this case, the drainage and the subsequent sinus came from a wound on the posterolateral aspect of the forearm; this wound was so small that we neglected to treat it primarily. It seems quite impossible that this hand and forearm could have survived with any kind of open treatment, without skin coverage or compression dressings.

The next case illustrates an unusual and unpredictable complication, in which immediate primary suture and conservative fracture treatment seem essential to survival of the extremity.

Case 5 (R. S.). While playing in a junk yard, an eight-year-old child was knocked down by an iron flywheel, weighing two tons. The flywheel passed over both legs, pinned the child down for half an hour, and was finally removed by means of a jack and crowbars. When seen in the accident room within an hour, the patient was in severe shock and showed compound fractures of the shafts of both bones of both legs, with severe deformity and fish-belly appearance of the lower half of the legs and the feet. The treatment consisted in immediate administration of plasma, débridement, primary suture, manipulative reduction of the fractures, and the application of compression dressings.

In the right leg spontaneous union, in good alignment and apposition, occurred within six weeks. The fracture of the left leg failed to unite. Five months after the accident, a sliding bone graft was performed. This failed to result in union, however: subsequently a dual bone graft, utilizing a typical onlay from the right tibia and the shaft of the left fibula, was carried out, with eventual union. The patient also required a lengthening of the heel cord on the grafted side. He was walking without support, eighteen months after the accident. Three years after the injury he had full function, with no deformity of either leg.

Since both legs were injured almost identically, each acted as a control for the other. At the time of the dual-graft operation, it was observed that the area of increased density in the distal fragment was completely devitalized; this bone was wholly devoid of circulation. Probably this was a result of the severe crushing injury and a cause of the original non-union, as well as the failure of the first bone graft.

The next case illustrates application of the same therapeutic principles to compound injuries of the skull, involving cerebrospinal fluid and brain ooze.

Case 6 (S. K.). A truck driver was in a head-on collision, his face being driven against the windshield frame. On admission to the Hospital he was unconscious; there was considerable ooze of cerebrospinal fluid and brain, an irregular lacerated wound of the forehead, and a crush fracture of the nasal and frontal bones (Figs. 3-A and 3-B). The status at the time of the first dressing, two weeks after the injury, is shown in Figure 3-C. The treatment consisted of débridement, intranasal correction of the fractured nasal bones, primary suture after frosting with sulfanilamide, and application of a compression dressing which included gauze fluffs and a sea sponge. No anaesthesia was necessary. One month after the accident, the patient returned to his regular work as a truck driver.

The seventh case illustrates the advantage of primary closure when a joint is so severely disrupted that arthrodesis is inevitable, and no immediate treatment of the fracture is indicated, other than mere approximation and the application of a skin-fitting plaster and a compression dressing.

Case 7 (G. K.). On March 6, 1944, while painting, the patient fell from a ladder, injuring his ankle. His injury on admission to the Hospital, three hours later, is shown in Figures 4-A and 4-B. The treatment included

Fig. 4-A

Roentgenograms show typical complete fracture-dislocation. No attempt at exact reduction has been made.

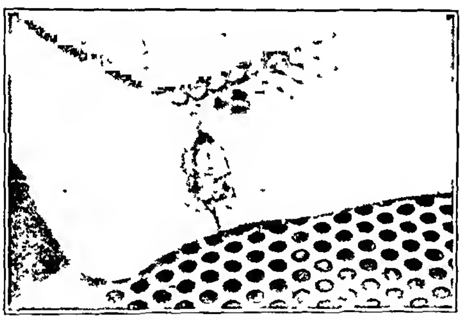

Fig. 4-B

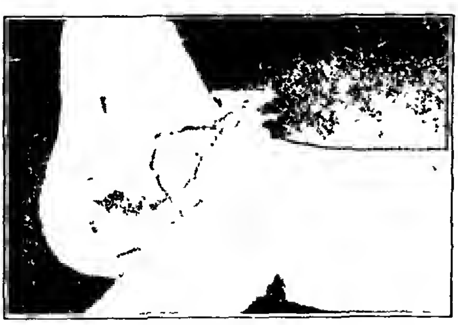

Fig. 4-C

Fig. 4-D

Fig. 4-B: Appearance of ankle on admission, three hours after fall from ladder. Treatment consisted of immediate débridement, saline irrigation, primary suture, and compression dressing.

Fig. 4-C: Appearance of wound at first dressing, two weeks after injury.

Fig. 4-D: [illegible] appearance, four months after arthrodc[illegible] synostosis.

immediate administration of plasma and maintenance of the sulfonamide level in the blood at five to ten milligrams per 100 cubic centimeters. Since the ankle joint was completely disrupted, no studied attempt was made to reduce the fragments accurately. The local treatment consisted of immediate débridement, irrigation with saline solution, primary suture, and the application of a compression dressing with gauze

fluffs, skin-fitting plaster, and elastic webbing bandage. Arthrodesis of the ankle and tibiofibular synostosis were performed on April 24, seven weeks after the injury. Two weeks later the wound was clean and dry (Fig. 4-C). The result four months after arthrodesis is shown in Figure 4-D. Three years after injury the patient has a stiff ankle, with good function of the leg and foot.

The importance of immediate closure in hastening the subsequent reconstructive surgery is obvious.

DISCUSSION

Because of variables involved in the individual case, it is extremely difficult to evaluate the merits of any single approach to the treatment of compound fractures. The kind and degree of contamination, the size and nature of the skin defect, the amount of bone exposed and the degree of shattering, the amount of blood loss, the degree of shock, the presence of other injuries, and the age and state of health of the individual prior to the accident,—all have a bearing on the outcome. It is possible, however, to evaluate certain general features from a study of the facts in a significant number of consecutive cases. Recent accounts of the results of delayed suture seem significant, but they are limited largely to battle casualties in which primary suture is impractical and hazardous. If the armamentarium and ability are at hand for execution of the proper careful débridement, internal fixation, skin-plastic operation, compression dressing, and treatment of shock within the usual time limit, delayed suture seems to add to the risk rather than to diminish it.

In the present series, the two cases of gas infection, one fatal and the other requiring amputation, are open to question. Whether these patients would have survived under a program of open treatment is speculative. The fatal case was that of a middle-aged school teacher whose tibia was soiled by implantation in the ground in the country. The wound was debrided; the tibia was plated; and a primary suture was done. Within thirty-six hours, fulminating gas gangrene developed and extended above the lower extremity; death occurred within forty-eight hours of the injury. At the first warning of high temperature the cast was removed, and crepitation was noted around a pinhole wound in the posterior aspect of the leg, which had been completely overlooked at the time of primary suture of the more obvious and severe wound. The case requiring amputation was a compound fracture-dislocation of the ankle, in which the talus was partly avulsed and in which it had seemed clear to the operator that, unless primary suture were executed immediately, a mid-leg amputation would be imperative. High temperature and crepitation immediately above the ankle, plus a positive culture, led to a Callander amputation.

Balanced against these two disasters are the remaining cases of the series: 146 living patients, including 131 whose wounds have healed by first intention. Fifty-six of these had compound fractures of the tibia with protrusion and soiling of the fragments; some resulted from street and some from rural accidents. The majority of the patients obtained union and function as promptly as though they had had simple fractures. In these fifty-six cases the penalties of open treatment, whether of delayed suture or of the Orr type, would have included the hazard of prolonged exposure of cortical bone to air; the usual subsequent sequestration of exposed cortex; the frequent non-union, later requiring bone-grafting under most unfavorable conditions; the almost inevitable mixed low-grade infection by putrefactive organisms, which results in massive scarring; the unsatisfactory surface covering and extensive retraction of skin; and the possibility, based upon past experience, that amputation might eventually become necessary.

It seems important to classify dirt-soiled wounds into three groups on the basis of the type of bacterial contamination to which they have been subjected: (1) Those occurring in urban households and machine shops are least contaminated; (2) those sustained in street accidents are more seriously contaminated; and (3) those occuring in suburban or rural surroundings exhibit dangerous contamination of bone and soft parts by the soil of

highly cultivated districts. All of the patients in this series were given prophylactic treatment, consisting of combined gas and tetanus antiserum. It is realized, however, that, in the case of soil-contaminated wounds, it is of the utmost importance to consider the advisability of open treatment. The fate of the patient will depend upon the experience and judgment of the operator who is familiar with both open and closed treatment, and upon his ability to perform a complete débridement. Since the most dangerous anaerobes are saprophytic, the wound should be left open unless the devitalized tissues can be removed completely.

SUMMARY

A series of 150 consecutive compound fractures has been treated by primary suture, partly with and partly without the advantage of the bacteriostatics, a blood bank, and a high-protein diet.

In respect to wound healing, bony union, prompt restoration of function, and the salvaging of extremities, the results have been superior to those obtained by previous methods.

Improved results are attributed, first, to the compression dressing; second, to immediate coverage of the surface defect with skin or a split-skin graft; and third, to immediate or delayed internal hairline reduction, with metallic fixation when indicated.

The hazard of primary suture is greatly reduced by penicillin and the availability of whole blood. Healing by first intention has been more frequent since the adoption of more radical excision of partly or wholly devitalized skin flaps. Temporary removal of the tourniquet has been found to be the only dependable aid in evaluating the vitality of the skin.

A thorough knowledge of and versatility in skin-plastic surgery are important for selection of the optimum covering of the individual skin defect. Preference is given to the approximation of relaxed flaps, whenever possible. Defects caused by relaxing incisions are covered, immediately or later, by split grafts.

Evaluation of the end results of compound fractures is facilitated by photographs of the external wound, made at the time of the usual admission roentgenogram, and repeated two weeks later at the time of the first dressing.

An attempt has been made to evaluate the therapeutic indications of each case on admission and to determine the factors which require immediate treatment. Definitive fracture treatment should frequently be postponed. It is usually advantageous to carry out simultaneously the treatment of shock and a careful débridement, followed immediately by closure of the skin and the application of a compression dressing.

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DISCUSSION

DR. H. EARLE CONWELL, BIRMINGHAM, ALABAMA: It is appropriate that Dr. Davis should present this discussion before a group of specialists. The technique he describes can be used only by surgeons who are thoroughly familiar with it; it is not to be used indiscriminately.

Even though Dr. Davis did not minimize the importance of soft-structure damage, many of these cases, in my opinion, would have responded to skeletal traction and later to some form of plastic procedure to the soft structures. We see cases in which too much internal fixation will bring about non-union and other complications. In certain cases good function may be obtained by the use of traction, as well as by the methods described by Dr. Davis.

The importance of thorough cleansing and débridement cannot be overemphasized; however, conservative débridement should always be carried out. I agree that in certain cases of compound fractures, internal fixation can be carried out primarily, but such cases form a small proportion.

DR. KELLOGG SPEED, CHICAGO, ILLINOIS: It is well known that a preponderating number of compound fractures in this country are cared for by practitioners and surgeons less highly trained than are to be found in this group. Consequently, while admiring Dr. Davis's results, it is my usual habit in a teaching hospital to employ simple means and more balanced skeletal traction to obtain and hold reduction of open fractures, after generous and complete débridement under the best surgical conditions. This is so whether the fracture is of the femur or the phalanx of a finger. In civil life, with the patient under hospital control, primary plating of an open fracture after débridement may succeed; infections will be minimized as the operator's experience progresses; and primary suture may nearly always be attempted, either by flap-shifting methods or by immediate skin-grafting on wounds which are difficult to close, followed by gentle compression dressings, such as Dr. Davis showed us. Also, we know that frequent redressings must be avoided. To expect these results from all operating practitioners is, however, still asking too much of our less intensely trained colleagues.

DR. ARTHUR DAVIS (closing): From long experience with this audience, I am prepared for criticism of a conservative and skeptical quality. I would like to ask, however: "Of what does conservatism consist?" A while ago the word radical was applied to wide incisions for exposure and drainage. Is it not more conservative to depend upon primary closure, predicated upon the conditions set forth in the paper, than to interfere with such bone and soft-parts repair by exposing deep cells to the damaging effects of atmosphere, et cetera?

Prior to 1936 the compound fractures at Hamot Hospital resulted very frequently in delayed union, non-union, prolonged arduous care, sequestration, and amputation. There were no compression dressings, skin plastics, standardized inert metals, skin grafts, sulfonamides, penicillin, or blood transfusions. Each swing of the pendulum finds us in a different mood, with new tools in our hands. This subject has swung between alternations of open and closed treatment for about one hundred and fifty years. The recently acquired knowledge in these fields requires reorientation of these different factors in relation to compound fractures.

The difference between the results in our own Hospital in the last ten years and in the ten years immediately preceding is as the difference between night and day. We do not lose extremities today. We expect union almost as promptly as though the fracture were simple; we convert the compound fracture to a simple one immediately (within a few hours of injury). I do not like to think of what might have happened to the fifty-six tibiae in this series if they had been treated by an open method. We do not plate immediately in all cases. We close the wounds primarily, after a careful débridement. Sometimes such débridement is impossible, because of the sacrifice of tissues vital to the extremity.

The reason for presenting this paper here rather than elsewhere is that this group is equipped to execute the exacting technique required. The goal in terms of prompt callus formation and prompt wound healing seems infinitely worth while. We in Erie, with the evidence of the two decades before us, could not possibly return to any kind of open treatment for the great majority of our compound fractures.

PRIMARY ANTERIOR CONGENITAL DISLOCATION OF THE HIP*

BY H. R. MCCARROLL, M.D., ST. LOUIS, MISSOURI

From Shriners' Hospital for Crippled Children, and Department of Surgery, Washington University School of Medicine, St. Louis

Ryerson, in 1907, first reported a case of primary anterior congenital dislocation of the hip. This apparently stimulated little interest in the subject, however, and a thorough search of the medical literature reveals no further reference to this distinct clinical entity until 1939. The fact that this type of dislocation is more difficult to treat than the more common posterior type was apparently not recognized.

In 1939, a series of ten cases with dislocation of the primary anterior type was reported by McCarroll and Crego. Further study of this condition over a period of twelve years revealed that the anterior dislocation is not so rare as was originally thought. In a series of 111 congenital dislocations of the hip, observed from 1935 to 1945, inclusive, the primary anterior type was encountered in twenty-five hips or 22.5 per cent. of the entire group. The clinical manifestations responsible for the classification of this type of dislocation were thoroughly covered in the author's initial report and will not be repeated. Observation over a period of eight additional years has brought no change in these diagnostic criteria.

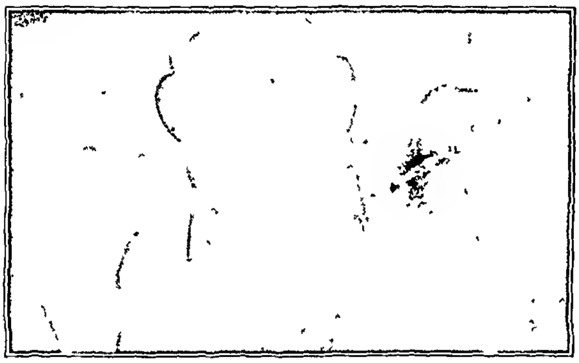

FIG. 1

J. M. Primary anterior congenital dislocation of the hip, ten years after massive anterior shelf operation. Patient obtained a fair result, with good motion; one-half inch of shortening and some pain resulted.

A plan of treatment was suggested in the previous report; this consisted of preliminary skeletal traction, followed by attempted closed reduction, and, after closed reduction had failed, by open reduction and the production of a superimposed massive anterior shelf. Every attempt was made to place the femoral head in the acetabulum, although in many instances it was impossible to maintain this reduction even at operation. Of the three hips in which the femoral head could be held in the acetabulum at the time of operation, recurrent dislocation into a true anterior position followed very early in two. The massive anterior shelf, extending from the posterior margin of the acetabulum to the anterior superior spine, was used, therefore, in order to afford stability and a weight-bearing surface for the femoral head, whether it was left in an anterior position at the time of open reduction or returned to this position after operation. Twelve operations of this type were performed, and the patients have been followed sufficiently long for their results to be evaluated with some measure of accuracy. This follow-up study varies from two to ten years, with an average of 5.8 years, for the twelve hips (Table I). Results from this surgical procedure were stated to be entirely satisfactory at the time of the initial report. Additional time, however, has proved the fallacy of this statement. Most of these hips have subsequently shown shortening of from one-quarter to three-quarters of an inch; and the patients have experienced limp, positive Trendelenburg sign, and pain, apparently from secondary traumatic arthritis (Figs. 1, 2, 3, and 4). In this series of twelve hips, five are now classified as fair and six as poor.

The additional hip (Fig. 5), classified as good, remained well seated in the acetabulum

* Read at the Annual Meeting of The American Orthopaedic Association, Hot Springs, Virginia, June 30, 1947.

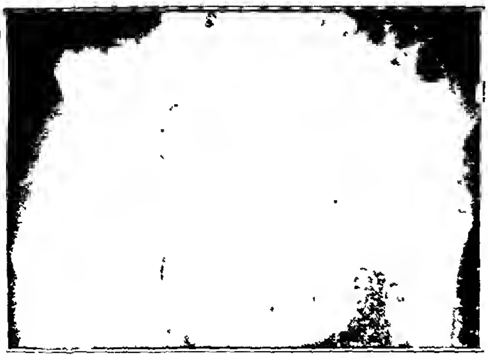

Fig. 2

Fig. 3

Fig. 2: F. T. Primary anterior congenital dislocation of the hip, six years after massive anterior shelf operation. The result was poor, with one and one-half inches of shortening, and some pain: motion was good. The shelf is undoubtedly still functioning.

Fig. 3: W. D. Primary anterior congenital dislocation of the hip, ten years after massive anterior shelf operation. The result was fair, with good motion, one-quarter inch of shortening, and no pain. The shelf still functions, but there has been no attempt to establish a smooth, rounded, weight-bearing surface.

Fig. 4

Fig. 5

Fig. 4: V. W. From a roentgenographic standpoint, this represents the best end result in the group treated by massive anterior shelf operation, but the patient was followed for only three years. The result is classed as fair, with fair motion, shortening of three-quarters of an inch, and no pain. The femoral head appears to be in the acetabulum, but is actually in an anterior position.

Fig. 5: A. B. (case 8 in the original report). This shows the one hip of the entire group, treated by massive anterior shelf operation, which remained seated in the acetabulum. The shelf has now entirely disappeared, ten years later. The result is classed as good, with good motion, no shortening, and no pain.

after open reduction and did not become redislocated, as did the others: the massive anterior shelf was gradually absorbed over a period of several years. A shelf will persist only when it is in active use, which was obviously not true in this instance. At the time of the initial report, it was felt that attempted closed reduction would invariably fail in this type of hip. It was also felt that recurrent anterior dislocation would follow open reduction, even though in this one hip (listed as Case 8[1]), reduction was still present. In spite of this, simple closed reduction has been attempted in each case as the initial procedure, and it has since proved successful in five hips (Figs. 6-A and 6-B) or 20 per cent. of the entire group. These five cases have now been followed for an average of 2.8 years. Their results are classified as good at this time, and some of them could easily be considered normal hips. Why these five hips of the typical primary anterior type should have responded to closed reduction, while others of the same clinical type failed, is not clear. It may, however, be due to the fact that the anterior rim of the acetabulum was not so defective in these five cases as in the others. The satisfactory results obtained in these cases raise the question as to whether or not the original clinical classification was correct: yet each patient showed the characteristics typical of the primary anterior type.

At the time the massive anterior shelf was being used, five cases were treated by

acetabular reconstruction. Reduction could be accomplished in these hips, and the oper
tion merely changed the angle of the superior rim of the acetabulum, in order to affo
a shelf or ledge of bone directly above. This was used in those instances in which the h

Fig. 6-A

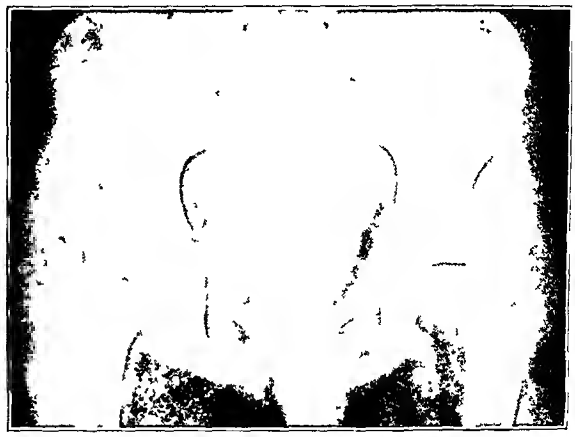

Fig. 6-B

Fig. 6-A: J. C. Primary anterior congenital dislocation of the hip in a child, two years of age. Treatment consisted of preliminary skeletal traction and closed reduction. (Supracondylar derotational osteotomy was performed as the final step in the treatment of all cases included in this report.)

Fig. 6-B: The same hip, four years after treatment. The result was classed as good, with normal motion, no shortening, and no pain. Treatment by closed reduction in this manner succeeded in only 20 per cent. of the cases.

Fig. 7-A

Fig. 7-B

Fig. 7-A: B. P. Untreated primary anterior congenital dislocation of the hip in a child, six years of age. Treatment consisted of skeletal traction; open reduction; and superior acetabular reconstruction, with an attempt to curve the shelf anteriorly and inferiorly to produce an anterior ledge.

Fig. 7-B: The same hip after five years. The result was classed as fair, since the hip remained reduced and stable, yet the motion was only fair and some pain was present.

Fig. 8-A

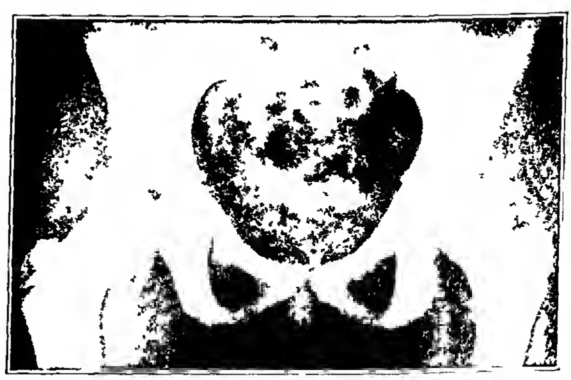

Fig. 8-B

Fig. 8-A: P. H. Untreated primary anterior congenital dislocation of the hip in a child, three years of age. Treatment consisted of skeletal traction, open reduction, and acetabular reconstruction superiorly.

Fig. 8-B: The same hip, three years later. The result is classed as fair. Even though the hip is still stable, has normal motion, and no pain, the femoral head is not well seated in the acetabulum. It tends to ride outward and anteriorly, and permanent reduction may not yet be assured.

seemed a little more stable at the time of open reduction. In two instances, however, an attempt was made to curve the shelf anteriorly and downward to form a partial curved ledge in front of the femoral head (Figs. 7-A and 7-B). This was difficult and unsatisfactory, because of an insufficient amount of bone at this point.

These five cases have now been followed for an average of 3.6 years. Only one hip can be rated as good at this time. Three are classified as fair and one as poor. The poor result is in a child who was seven years of age at the time of operation. After two years the hip shows very little motion; functionally it is poor; and there is still some question as to whether or not reduction will be permanent. Of the group classified as fair, pain is present in one after five years (Figs. 7-A and 7-B) and two are questionable from the standpoint of permanent reduction. The hips show some tendency to slip forward in the acetabula (Figs. 8-A and 8-B), even though they have not actually become redislocated. Even if results in all five cases of acetabular reconstruction were satisfactory, this method could still not be relied upon as a satisfactory means of treatment. The twelve hips in which a massive anterior shelf was formed also had the equivalent of a superior acetabular reconstruction, since the shelf was started at the posterior rim of the acetabulum. Reduction was still possible in only one hip; this reduction was maintained.

In one patient (Figs. 10-A, 10-B, and 10-C), several attempts at closed reduction were unsuccessful, and the femoral head could not be held in the acetabulum even at open operation. The acetabulum in this case was deepened by removal of its articular cartilage and considerable bone from its depth. In this way an anterior rim or ledge was developed in the acetabulum, and the head remained seated. The articular cartilage of the femoral head was placed in direct contact with the cancellous bone of the acetabular bed, without the use of an autogenous or foreign arthroplasty medium. After four years, the result in this hip can be classified as fair. The hip has not become redislocated, although the femoral head is riding at the outer edge of the acetabulum and, from a roentgenographic standpoint, does not appear very stable. The motion in this hip is fair, and already there is evidence of progressive traumatic arthritis in the joint. Its appearance, even at the time of operation, did not justify another attempt at reduction by the same method.

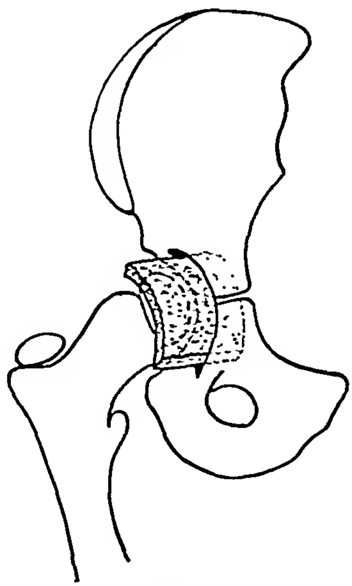

Fig. 9

Diagram showing the type and location of free graft, used in the anterior buttress operation. The graft is driven intracapsularly into the anterior rim of the acetabulum, allowing it to project laterally in front of the head and neck of the femur.

It has always seemed wise in the management of these hips to maintain the architecture of the two articular surfaces, if at all possible. This accounts for our persistent effort in most instances to avoid the use of some form of arthroplasty. Following this criterion, still another form of surgical reconstruction has been attempted,—namely, the use of the anterior buttress. The basic underlying anomaly in the primary anterior congenital dislocation is a defect in the anterior acetabular rim. Attempts were made to repair this in some of the earlier operations, in exactly the same way that the superior rim of the acetabulum is reconstructed. This was never successful, however, because of an insufficient amount of bone along the anterior portion of the acetabulum. One final attempt has been made to accomplish this by means of a large free graft, removed from the wing of the ilium, and which, for lack of a better term, is called the anterior buttress (Fig. 9). This large graft is curved slightly in its lateral plane and driven into a wedge, cut along the anterior rim of the acetabulum. The mass of the graft is allowed to project laterally, directly in front of the femoral head. This was first

Fig. 10-A

Fig. 10-B

Fig. 10-C

Fig. 10-A: W. W. Untreated primary anterior congenital dislocation of the hip in a child, seven and one-half years of age. Attempts at closed reduction failed three times.

Fig. 10-B: The same hip, three years later, after the third attempt at closed reduction had failed. At this time open reduction and deepening of the acetabulum were performed.

Fig. 10-C: Four years after operation, the result is classed as only fair. Motion is fair, there is no pain, and the hip remains stable; yet the femoral head is riding near the outer rim of the acetabulum, and considerable traumatic arthritis is apparent.

Fig. 11-A

Fig. 11-B

Fig. 12

Fig. 11-A: S. S. Primary anterior congenital dislocation of the hip, eight years after massive anterior shelf operation. The result is classed as poor because of pain, limp, and one-half inch of shortening. Open reduction and anterior buttress operation were performed at this time.

Fig. 11-B: Fifteen months after anterior buttress operation, the result is classed as fair. Reduction has been maintained; there is good motion; and no shortening, pain, or limp are present. The femoral head is not seated deeply in the acetabulum, however, and the superior acetabular rim appears questionable. The anterior buttress can be seen, and has prevented a recurrent anterior dislocation. The original anterior shelf is now disappearing, owing to lack of use.

Fig. 12: L. B. Primary anterior congenital dislocation of the hip, as seen fifteen months after anterior buttress operation and simultaneous superior acetabular reconstruction. The anterior buttress can be seen, a portion of it being attached to the acetabulum. This has, at least until now, prevented a recurrent anterior dislocation. The femoral head is riding far out of the acetabulum, however, and its position does not appear very secure. The result is classed as fair.

TABLE I

RESULTS IN TWENTY-FIVE HIPS WITH PRIMARY ANTERIOR CONGENITAL DISLOCATION

Treatment	No. of Hips	Average Follow-up (*Years*)	Results		
			Good	Fair	Poor
Massive anterior shelf	12	5.8	1	5	6
Successful closed reduction	5	2.8	5	0	0
Acetabular reconstruction superiorly	5	3.6	1	3	1
Deepening of acetabulum	1	4	0	1	0
Anterior buttress	2	1.3	0	2	0
No treatment	1				

attempted by placing the graft extracapsularly, but it was impossible to hold the graft in position in this manner. Later the graft was placed inside the capsule and the capsule was sutured over it, in order to maintain the correct position. Technically, this is a difficult procedure. The anterior portion of the acetabulum is often too poorly developed to permit a graft of this type to be inserted and to project directly laterally, in front of the femoral head. In these instances the graft is simply laid across the front of the hip joint, with its base overlying the denuded acetabular rim, and anchored inside the joint capsule. At times, it has been very difficult to visualize this graft by roentgenogram. The visualized portion of the graft has at other times shown no apparent connection with the anterior rim of the acetabulum, but appears to lie inside the joint, opposite the femoral head or the femoral neck. Whether or not, therefore, the bone graft actually is attached and holds in the manner intended, is impossible to state in many instances. An operation of this type may serve simply to produce an anterior ledge for the acetabulum by extensive postoperative formation of scar tissue.*

Late end-result studies are not possible on hips treated by the establishment of an anterior buttress, and the method is included only as a preliminary report, to show what is being attempted in this type of hip at the moment. It has been used in two hips of the primary anterior type (Figs. 11-A, 11-B, and 12). It has also been used in three primary posterior dislocations, not included in this series, in which redislocation into an anterior position occurred after treatment. No recurrent dislocations have as yet been encountered after this procedure. In the two primary anterior dislocations included in this series, the results can be classified as fair after fifteen months. In one hip (Figs. 11-A and 11-B) a massive anterior shelf had been constructed eight years previously, and proved unsatisfactory because of pain. A simultaneous superior acetabular reconstruction was performed in the second case (Fig. 12) because of an inadequate superior rim, and this amount of surgery probably accounts for the fact that the residual motion is limited to 60 degrees.

CONCLUSIONS

At present it may be safely stated that no universally satisfactory method has been found for treating the primary anterior dislocation which cannot be corrected by closed reduction. In an attempt to accomplish this without disturbing the architecture of the articular surfaces, the use of the anterior buttress will be given further trial. If this proves unsatisfactory, some type of arthroplasty would seem to be the next logical step.

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* Supracondylar derotational osteotomy was performed as the final step in the treatment of all cases included in this report.

RESULTS OF TREATMENT OF IRREDUCIBLE CONGENITAL DISLOCATION OF THE HIP BY ARTHRODESIS *

BY CHARLES J. FRANKEL, M.D., CHARLOTTESVILLE, VIRGINIA

From the Department of Orthopaedic Surgery, University of Virginia Hospital, Charlottesville, and the Shriners' Hospital, St. Louis, Missouri

The choice of a proper palliative procedure for treatment of unilateral, irreducible congenital dislocation of the hip has always been most difficult. In 1940, a study was made, by the author, of the cases treated by shelving, osteotomy, and arthrodesis at the Shriners' Hospital in St. Louis and at the University of Virginia Hospital, and the literature was reviewed [1].

The conclusions reached, based on the study of our cases and the results in cases treated throughout the country, were that, in the treatment of this condition, arthrodesis offered the patient the best prognosis, for relief of pain and improved function. None of the other palliative procedures seemed to assure consistently good end results with freedom from pain. We were of the opinion that a child whose economic status was such as to make it almost certain that he or she would, in later life, be required to earn his or her own living, and whose work probably would not be sedentary, would be able to carry on best with a stiff, but painless, hip.

Fourteen patients in the younger group were treated by arthrodesis. Only eight, however, had adequate follow-up studies. The youngest child was seven years of age and the oldest was fifteen. The average age was twelve. The longest follow-up period was twenty-one years; the shortest was four and one-half years; and the average was fourteen years. Seven of the patients were girls.

PROCEDURE

All of the hips were pulled down as far as possible by preliminary skeletal traction, which was applied for from three to eight weeks prior to surgery.

Four patients had initial extra-artieular fusions in which tibial or trochanteric grafts were driven through the head distally and the ilium proximally. In one case a secondary extra-articular fusion was performed. The hips were placed in the best position for fusion, and osteotomies were performed later where it was necessary to provide a better functional position.

Fusion was obtained in two hips by simply denuding the femoral heads and placing them in a trap door in the ilium. In one instance, a flap from the ilium was turned down and driven through the femoral head. The flap was held in place by two Vitallium nails. Another hip was fused simply by the use of a long Smith-Petersen nail, which was driven through the femoral neck and head deep into the thick portion of the ilium.

RESULTS

One of the two hips in which no graft was applied failed to fuse. Later, when a graft was used, solid arthrodesis resulted. All of the hips fused well. The average time required for fusion was two years. In several hips, fusion took place in from eleven to fourteen months, while the others required from thirty-two to thirty-eight months.

Prior to traction and surgery, shortening averaged three and one-fifth inches in the eight cases followed. After arthrodesis, shortening averaged three-quarters of an inch; the average correction was two and two-fifths inches. In one case, an epiphyseal arrest

* Presented at the Annual Meeting of The American Orthopaedic Association, Hot Springs, Virginia, June 30, 1947.

Fig. 1-A

Fig. 1-B

Fig. 1-C

Fig. 1-A: Case 1, B. L. Dislocation of hip. Three inches of shortening present on September 5, 1939.
Fig. 1-B: Hip after treatment for six weeks with forty-six pounds of traction.
Fig. 1-C: January 27, 1943. Arthrodesis was performed with the hip in good position.

Fig. 2-A

Fig. 2-B

Fig. 2-C

Fig. 2-A: Case 2, D. M. Dislocation of hip with three and one-half inches of shortening present on June 2, 1931.
Fig. 2-B: Hip after traction of thirty pounds for twenty-five days.
Fig. 2-C: March 29, 1938. Seven years after first attempt at arthrodesis and osteotomy.

has been performed with no apparent change in the amount of shortening, which, five years after the arrest, is still one and one-half inches.

Our results were tabulated according to a modified standard set up by Galeazzi's clinic and used by Steindler in his report in 1935. All of the patients to date show good results: Their shortening and limp are slight; none have pain; and fatigue is mild in three cases. None of the patients have arthritic complaints, and none consider the stiff hip a major disability.

CASE REPORTS

Case 1. B. L., a twelve-year-old white girl, had three inches of shortening. Forty-six pounds of traction was applied for six weeks, and then a shelf operation was performed which failed. One month later, fifty pounds of traction was applied for thirty days. This was followed by an extra-articular arthrodesis with a tibial graft. The hip was immobilized for eight months in a hip spica. The end results were three-quarters of an inch of shortening and no complications from traction.

Case 2. D. M., a fourteen-year-old white girl, had three and one-half inches of shortening. Thirty pounds of skeletal traction was applied for twenty-five days, followed by an intra-articular arthrodesis by simply denuding the femur and acetabulum of cartilage. Immobilization was carried out for eight months, but there was no evidence of arthrodesis. The patient was sent home. She returned in six years, and a subtrochanteric osteotomy was performed. Arthrodesis occurred after six months of immobilization. The end results were five-eighths of an inch of shortening, no pain, and no complications from the pin.

Fig. 3-A

Fig. 3-B

Fig. 3-A: Case 3, I. C. Dislocation of hip. Three inches of shortening present on May 29, 1936.
Fig. 3-B: Arthrodesis followed three weeks of fifty-pound traction. Subtrochanteric osteotomy was performed to improve position. Results on January 11, 1939.

Fig. 4-A

Fig. 4-B

Fig. 4-A: Case 4, L. C. Dislocation of hip and three inches of shortening present on May 19, 1926.
Fig. 4-B: Arthrodesis three years after grafting.

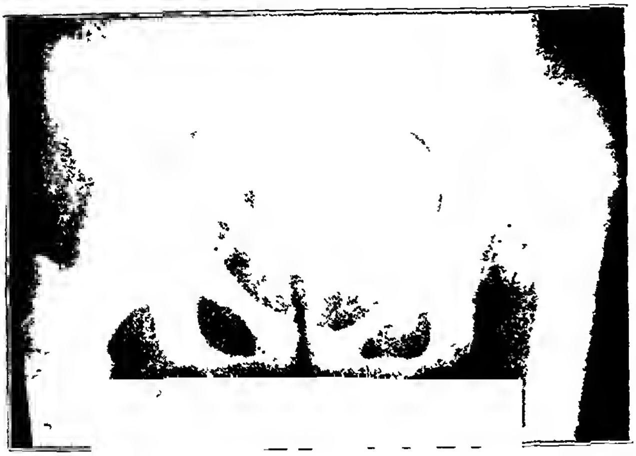

FIG. 5-A

FIG. 5-B

Fig. 5-A: Case 5, L. M. Dislocation of hip with three and one-half inches of shortening present on November 6, 1925.

Fig. 5-B: Four years after arthrodesis.

Fig. 6-A: Case 6, P. O. Dislocation of hip with three inches of shortening present on September 5, 1939.

Fig. 6-B: Hip after treatment for six weeks with forty pounds of traction.

Fig. 6-C: Four years after osteotomy and arthrodesis.

FIG. 6-A

FIG. 6-B

FIG. 6-C

CASE 3. I. C., a fourteen-year-old white girl, had three inches of shortening. Fifty pounds of traction was applied for three weeks. Intra-articular arthrodesis was done; but simple denuding of the head and acetabulum was unsuccessful. This was followed, seventeen months later, by an extra-articular arthrodesis with a tibial graft and a subtrochanteric osteotomy. The hip was immobilized for eight months. The end result was an excellent fusion and a painless hip. One-half inch of shortening remained; there were no complications from the pin.

CASE 4. L. C., a fifteen-year-old white girl, had three inches of shortening. Seventy pounds of traction was applied for sixty days, followed by an extra-articular arthrodesis with a trochanteric graft. The hip was immobilized for eight months. Good fusion and a painless hip resulted. There was slight fatigue, and three-quarters of an inch of shortening remained There were no complications from the pin.

CASE 5. L. M., a thirteen-year-old white girl, had three and one-half inches of shortening. She was

Fig. 7-A

Fig. 7-B

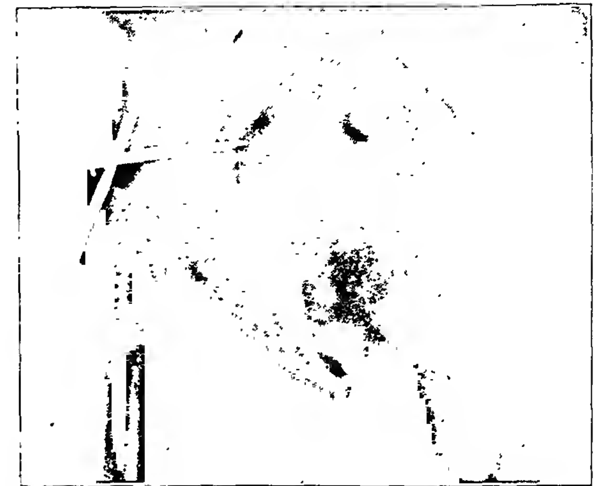

Fig. 7-C

Fig. 7-A: Case 7, E. C. Dislocation of hip and three inches of shortening.
Fig. 7-B: After treatment for three weeks with thirty pounds of traction.
Fig. 7-C: Two years after arthrodesis.

Fig. 8-A

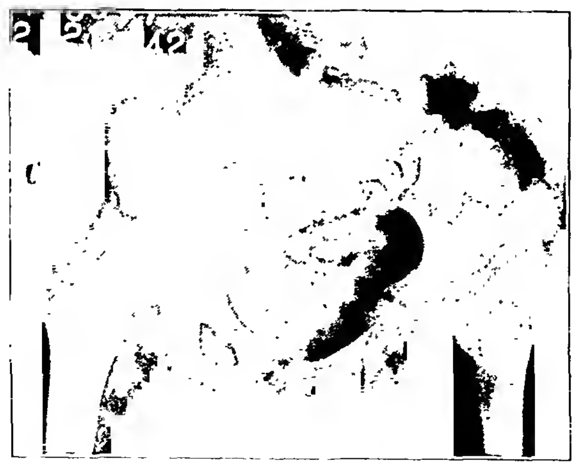

Fig. 8-B

Fig. 8-C

Fig. 8-A: Case 8, P. L. Dislocation of hip and three and one-half inches of shortening.
Fig. 8-B: After treatment for three weeks with traction of forty pounds.
Fig. 8-C: One year after arthrodesis.

treated by fifty pounds of traction for thirty days, followed by simple extra-articular fusion. The hip was immobilized for eight months. The result was good fusion with three-quarters of an inch of shortening and no pain. No complications from the pin occurred.

Case 6. P. O., a thirteen-year-old white girl, had three inches of shortening. Forty pounds of traction was applied for six weeks, followed by extra-articular application of a massive tibial graft. After immobilization for six months, subtrochanteric osteotomy was done to improve the position of the hip. Immobilization for ten weeks followed. Good fusion resulted. There was one inch of shortening, but there were no complications from the pin.

Case 7. E. C., an eight-year-old colored girl with three inches of shortening, was treated by thirty pounds of traction for three weeks. This was followed by application of an iliac extra-articular graft and Vitallium nails. The hip was immobilized for six months. Fusion took place in one year. The end results were good fusion and a painless hip; one inch of shortening remained. No complication from the pin occurred.

Case 8. P. L., an eleven-year-old white boy, had three and one-half inches of shortening. He was treated by application of forty pounds of traction for three weeks, followed by arthrodesis with a four-inch Smith-Petersen nail, which was driven through the neck and head of the femur into the ilium. The boy was immobilized in a cast for four months. Clinical union occurred in one year. A painless hip, three-quarters of an inch of shortening, and good fusion resulted. No complications occurred from the pin.

Many of the early cases were treated by Dr. Leroy Abbott. Kirschner wires and later bicycle spokes were used for skeletal traction and were placed through the lower third of the femur. No sign of nerve palsy or any circulatory difficulty developed in any of the cases. In two cases, not included in this series, small ring sequestra developed about the wires. These were thought to be due either to the high-speed electric drill used or to the side-to-side movement of the wire. This complication has been eliminated by the use of a slower-speed drill and threaded wires. All of the children complained of pain after a week or two of traction, but mild sedation was adequate to carry them through the treatment. No accurate check was made of changes in pulse rate. Countertraction was obtained by extremely high elevation of the foot of the bed.

CONCLUSIONS

Arthrodesis, in cases of patients with unilateral, irreducible congenital dislocation, assures the best results as far as pain and fatigue are concerned. The operation should be limited to patients of the lower economic level. Sociologists estimate that a child has one chance in twelve of rising from a low social-economic level to the so-called middle-class level. If such a child must expect to earn his or her living through manual labor, a painless hip is almost a necessity.

In the small series of cases presented, uniformly good results were obtained by arthrodesis. Other clinics have also reported similar results in their small series of cases [2].

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FOLLOW-UP STUDY OF THE EARLY TREATMENT OF CONGENITAL DISLOCATION OF THE HIP *

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The early treatment of congenital dislocation of the hip in this Clinic is based on the premise that forceful manipulation and reduction, with prolonged plaster immobilization, constitute unsound treatment. In the authors' experience, this method, formerly known as the "bloodless reduction", has proved to be unjustified.

Our results from the use of forceful manipulation have been discouraging from the standpoint both of immediate effect and of long-term observation. Experiences here closely parallel the results reported by Gill in a recent follow-up study of this method of treatment of congenital dislocation of the hip.

The groundwork for our present management of congenital dislocation of the hip was laid prior to 1933, and the preliminary work has already been reported by Crego and by McCarroll and Crego. These reports discussed the objections to "bloodless reduction"; therefore, further discussion will not be offered in the present follow-up study. In none of the present series of cases has it been found necessary or even advisable to resort to forcible manipulation and immobilization in the frog position, in order to obtain a satisfactory result.

The present analysis deals with follow-up observations in those cases treated initially before the children had passed their seventh year. Four of the total number were treated first between the ages of one and two years; four were treated initially between the ages of six and seven years; and seventy were treated first between the ages of two and six years. The correlation of end results with respect to age at the time of initial treatment is shown in Graph I, and from this it can readily be seen that the optimum age for treatment lies between two and five years. The greatest percentage of normal end results was obtained in that group treated first at two years of age.

The cases reported have been followed for a minimum of one year and a maximum of fifteen years after the completion of treatment. In approximately 50 per cent. of the total number of hips, the follow-up study has been continued for six years or more.

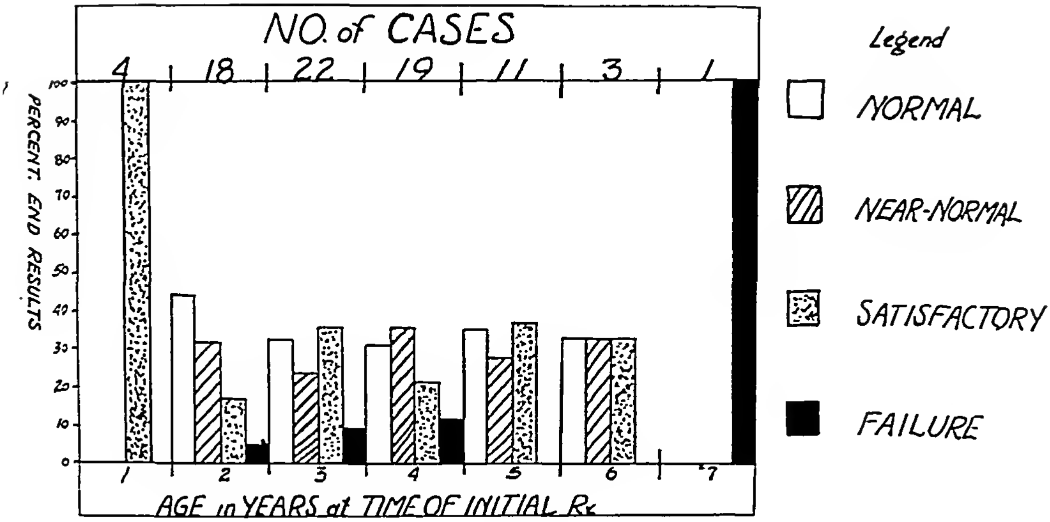
Since 1933, a total of ninety-three dislocations of the hip, within the age group reported, have been seen. Of these, sixty-one are classified as primary posterior dislocations, seventeen as primary upward luxations or subluxations, and fifteen as primary anterior dislocations. The criteria for such a classification have already been presented in detail by McCarroll and Crego.

The present analysis deals with those hips classified as having primary posterior dislocation, primary upward luxation, or subluxation, and involves seventy-eight hips in fifty-two patients. The fifteen primary anterior dislocations are being analyzed in a separate report by McCarroll, which appears in this issue of *The Journal*, and will not be included here.

METHOD OF TREATMENT

Treatment of congenital dislocation of the hip is directed toward restoring the hip joint to a state as nearly normal as is possible, both functionally and anatomically (structurally). Sound treatment requires, first, that all the factors contributing to the abnormality of the hip joint be recognized, and second, that these factors be made as nearly normal as possible.

* Read at the Annual Meeting of The American Orthopaedic Association, Hot Springs, Virginia, June 30, 1947.



GRAPH I

Shows relationship of age at initial treatment to end result.

In analyzing a hip for treatment, the various factors to be considered, which may be present at the time of initial examination or may be observed during treatment, are:

1. The dislocation itself;
2. Anomalies of the head and neck of the femur;
3. Anomalies of the capsule;
4. Anomalies of the acetabulum.

We believe that the logical treatment of congenital dislocation of the hip requires that any abnormality which presents itself, and prevents either reduction initially or maintenance of the reduction, should be corrected when the necessity first arises.

The Dislocation Itself

In seventy-one of the seventy-eight hips, the dislocations were complete,—that is, the head of the femur lay completely outside the acetabulum in either a posterior or an

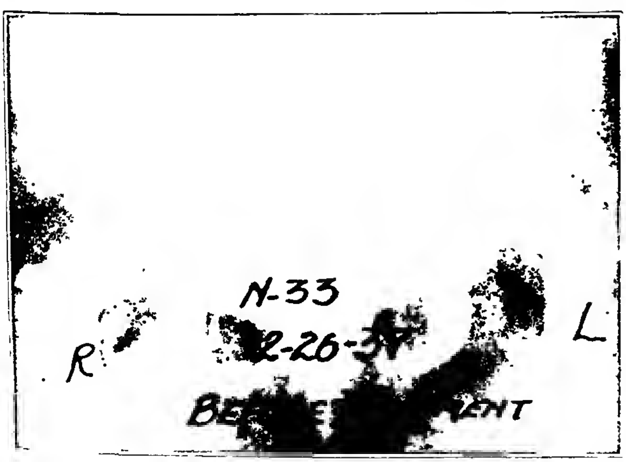


FIG. 1

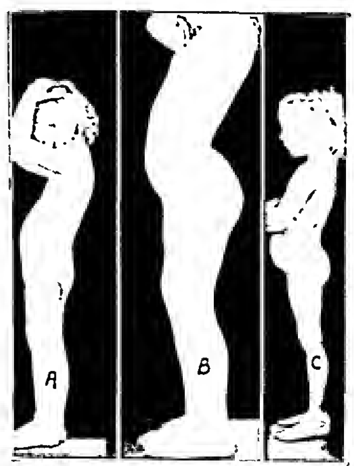


FIG. 2

FIG. 1 Bilateral dislocation in which the right hip is incompletely or partially dislocated; the left is completely dislocated.

FIG. 2: Showing clinical appearance in different types of dislocations.
A: Bilateral primary anterior dislocation.
B: Bilateral primary posterior dislocation. C: Bilateral upward luxation.

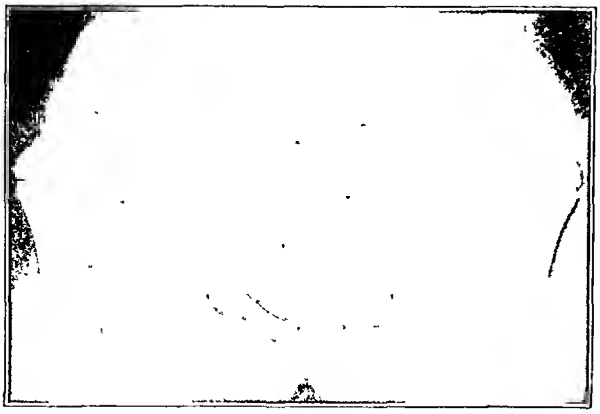


Fig. 3

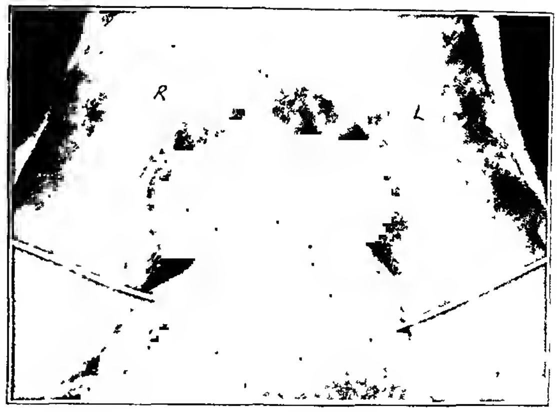


Fig. 4

Fig. 3: Congenital partial absence of femoral neck. Such anomalies prevent maintenance of reduction by any means.

Fig. 4: Showing method of correcting femoral torsion by supracondylar osteotomy. This procedure is seldom done on both sides simultaneously.

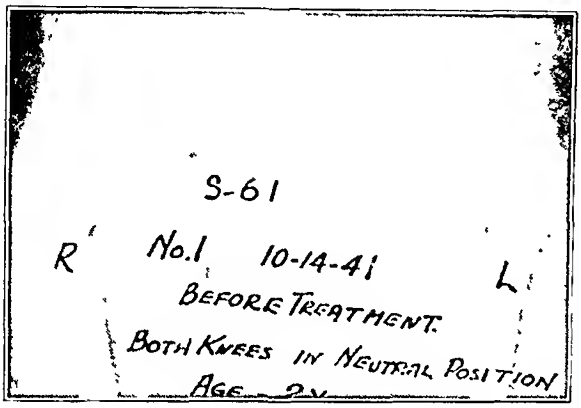


Fig. 5-A

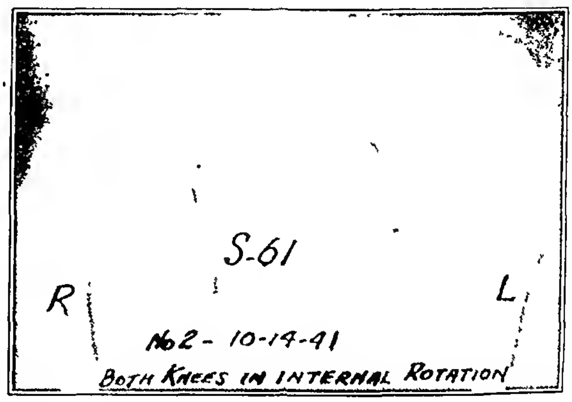


Fig. 5-B

Method of determining presence of femoral torsion.

Fig. 5-A: Anteroposterior view of pelvis, with both knees in neutral position. Torsion is present bilaterally.

Fig. 5-B: Both knees are in 70 degrees of internal rotation, showing normal angles of femoral neck.

Fig. 5-C: Showing result five years later. Each hip was treated by skeletal traction, followed by derotational osteotomy to compensate for femoral torsion. Treatment was started at two years of age. The left hip was treated completely before treatment was started on the right hip. The results were graded as normal bilaterally, five years after treatment was begun.

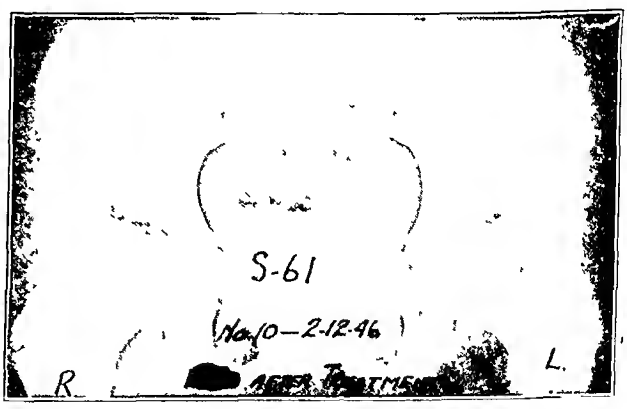


Fig. 5-C

upward position. The other seven were incomplete dislocations or subluxations, in which the head of the femur lay outside the socket, with partial upward displacement (Fig. 1).

In order to bring the head of the femur from its position of dislocation or subluxation to a position where it could be placed into the acetabulum without violent force, two methods were used,—manipulation and traction. Manipulation, as used in this Clinic, means that, with no more force than is required to demonstrate telescoping, the head of the femur is brought within the acetabular fossa. Traction, either skeletal or skin (if sufficient), was used as a preliminary to reduction in all cases which would require more than the amount of force of manipulation to place the head within the acetabulum. Forcible manipulation under anaesthesia has not been used in any of these cases.

When traction is used to pull the head of the femur down opposite the acetabulum,

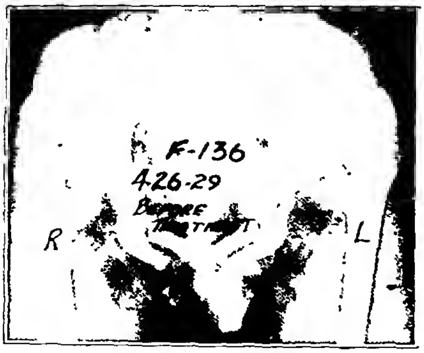


Fig. 6-A

Fig. 6-B

Roentgenographic appearance, eight years after beginning of treatment (Fig. 6-B), in a case classified as normal, right, and failure, left. Treatment was started at four years of age in this case of bilateral posterior dislocation. The right hip was treated by skeletal traction after tenotomy of the hip flexors and adductors, followed by open reduction. Femoral torsion was not present at open reduction. The left hip was treated by skeletal traction, and stable reduction was achieved. Torsion was present but was purposely not corrected, to demonstrate that it will not correct itself spontaneously. The left hip was redislocated to an anterior position two years later, because of failure to correct the torsion of the femoral neck.

the head of the femur should be brought into the proper position within a two-week period. Traction is continued, the position obtained being maintained for a total of four weeks. Following this, and usually with the use of an anaesthetic, the head of the femur can easily be placed into the acetabulum by internal rotation and abduction of the thigh. In this position plaster is applied, and the reduction is maintained in plaster for three months before further treatment, if indicated, is carried out.

Five of the seven subluxations were reduced by simple manipulation without an anaesthetic, and did not require preliminary skeletal traction. In two of the five, reduction was achieved spontaneously by the hips being placed in wide abduction and internal rotation. These two required that femoral torsion be corrected, in order to maintain reduction. In the other three, spontaneous reduction occurred during treatment for complete dislocation in the opposite hip, and the subluxations remained reduced without further treatment. Of the remaining two subluxations, preliminary skeletal traction was required to bring the head of the femur opposite the acetabulum, preparatory to reduction.

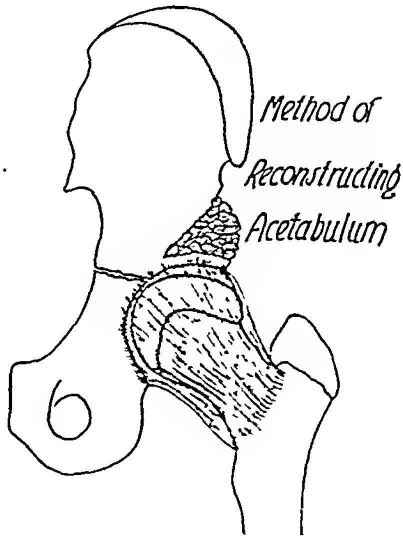


Fig. 7

Diagrammatic sketch shows the method of acetabular reconstruction used in this series.

The seventy-one complete dislocations required preliminary traction to bring the head of the femur into a position where it could be placed into the acetabulum. Usually skeletal traction was required, since in only twelve cases could satisfactory pull be applied by means of adhesive skin traction.

Gill reported that in thirty (approximately 9 per cent.) of his cases, the hips were irreducible by bloodless reduction in patients under four years of age. In the authors' series it was possible in every instance to bring the head of the femur into a satisfactory relationship with the acetabulum, in order to permit reduction; but stable seating *of the* hip joint after traction, as the *only initial* treatment, was possible in only about 55 per cent. of the total cases.

This observation indicates that correcting the malposition of the head of the femur alone resulted in stable seating of the joint in slightly more than one-half of the total hips treated. For many of this number, correction of other abnormalities was required to *main-*

tain stable reduction. In only eleven of this series, or 14 per cent., was traction or manipu lation alone sufficient to maintain stable reduction.

In addition to correction of the malposition of the femoral head, it was necessary t correct associated abnormalities, in about 85 per cent. of the total hips treated, before stable reduction was effected by the initial treatment.

In addition to the *degree* of dislocation, we take into consideration the *type* of disloca tion, and have found, as reported by McCarroll and Crego, that primary posterior disloca tion and upward luxations and subluxations are more amenable to treatment than ar primary anterior dislocations. This is of value from a prognostic standpoint (Fig. 2).

Anomalies of the Head and Neck

Certain anomalies, such as absence or partial absence of the neck of the femur, preven maintenance of reduction by any form of treatment. The so-called "reptilian" hips mentioned by Stewart, and those with absence of both the head and neck, are not amenabl to reduction. In these instances a pelvic-support type of osteotomy of the femur is needed This particular problem was not encountered in the present series (Fig. 3).

Femoral torsion, in which the head and neck of the femur are angulated forward to the normal position with relation to the coronal plane of the femur, was observed ir seventy-one cases. This anomaly, if uncorrected, results in redislocation of the hip, witl the head resting in an anterior position. The hip joint is not restored anatomically unless torsion is corrected, and experience has shown that the torsion does not correct itself[2]

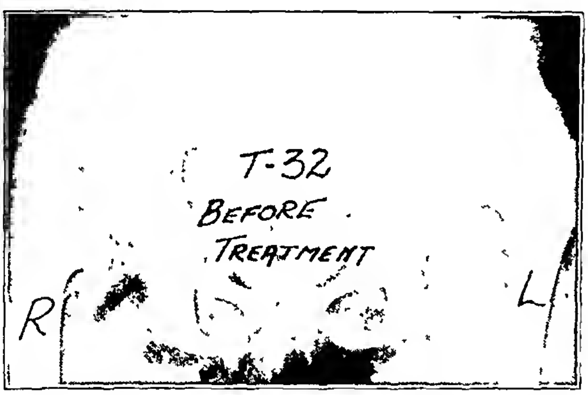


Fig. 8-A

Fig. 8-B

Roentgenographic appearance of results classified as satisfactory. Posterior dislocation is present bilaterally. The left hip was treated at three and one-half years of age; the right hip was treated at five years of age. Treatment in both instances consisted of skeletal traction, followed by correction of femoral torsion. Fig. 8-B shows appearance three and one-half years after treatment was begun.

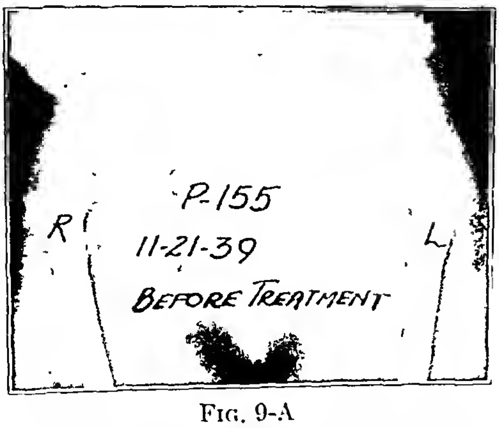


Fig. 9-A

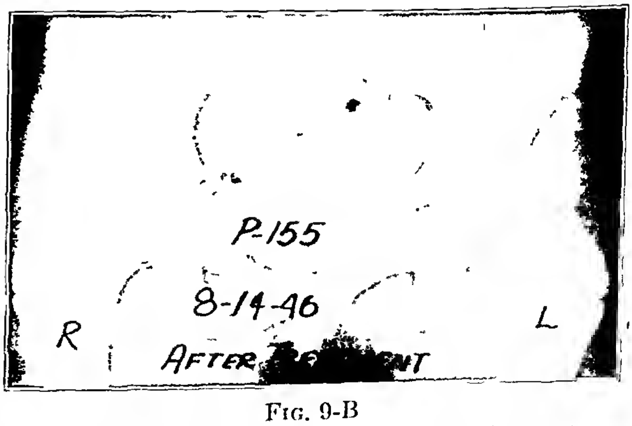


Fig. 9-B

Roentgenographic appearance, seven years after beginning of treatment, of results classified as normal, right, and near normal, left. This was a bilateral posterior dislocation. Treatment was started at three years of age and each hip was treated separately. Treatment consisted of preliminary skeletal traction, followed by correction of femoral torsion on both sides.

FIG. 10-A

FIG. 10-B

M-66. Bilateral posterior dislocation. Treatment was begun at two and one-half years of age. The right hip was treated by skeletal traction, but became redislocated six months later: it was subsequently treated by acetabular reconstruction and derotational osteotomy. The left hip was treated by skeletal traction only.

The result was graded as normal bilaterally, eleven years after the beginning of treatment.

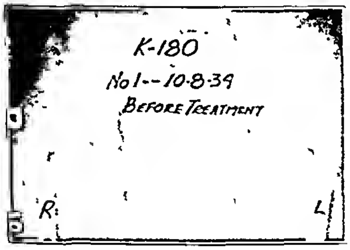


FIG. 11-A

K-180. Bilateral posterior dislocation. Treatment was begun at three years of age. The right hip, treated first, required skeletal traction only. The left hip was treated by preliminary skeletal traction and derotational osteotomy.

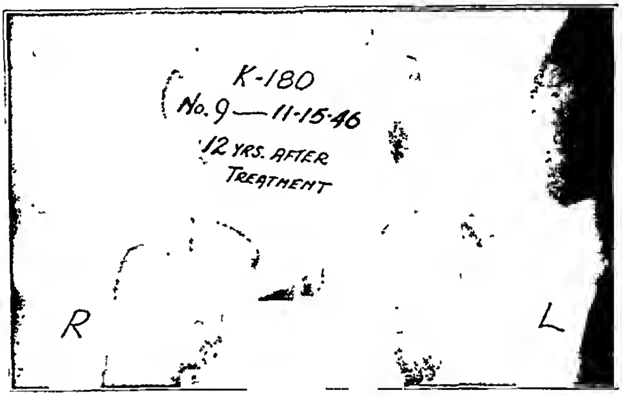


FIG. 11-B

Results were graded as normal bilaterally, twelve years after beginning of treatment.

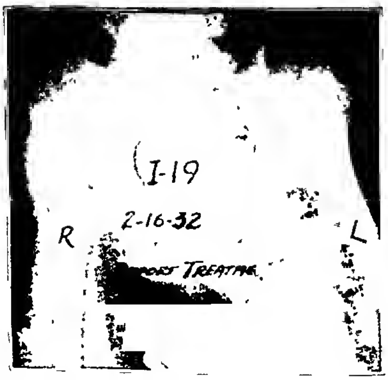


FIG. 12-A

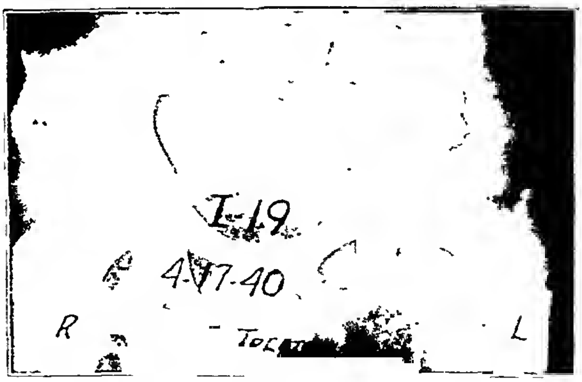


FIG. 12-B

I-19. Treatment was begun at four years of age. The right hip was treated by tenotomy of the hip flexors and adductors, with skin traction, followed by open reduction and acetabular reconstruction. The left hip was treated by tenotomy of the hip flexors and adductors, with skeletal traction and derotational osteotomy; it became redislocated three years later, and was again treated by skeletal traction and acetabular reconstruction.

Eight years after the beginning of treatment, the results were graded as near normal, right, and normal, left.

TABLE I

RESULTS IN HIPS REQUIRING ACETABULAR RECONSTRUCTION

Results	Age at Time of Acetabular Reconstruction						Total
	1 Year	2 Years	3 Years	4 Years	5 Years	6 to 15 Years	
Normal	0	1	2	1	1	4	9
Near normal	0	1	1	2	3	0	7
Satisfactory	0	1	5	6	1	3	16
Failures*	1	1	2	2	1	1	8
Totals	1	4	10	11	6	8	40

* In 3 of these cases a secondary acetabular reconstruction was done, with satisfactory results. The first reconstructions in these patients were done at 1, 4, and 5 years of age; secondary reconstructions were done at 4, 5, and 8 years of age, respectively.

Surgical correction by means of femoral osteotomy has been used to compensate for torsion sufficient to interfere with the maintenance of stable reduction of the hip (Fig. 4).

Before treatment, roentgenograms have been taken routinely of the pelvis with both femora in neutral position, and with both femora internally rotated. In this manner femoral torsion can be demonstrated easily, as shown in Figures 5-A, 5-B, and 5-C. In seventy-one hips of the present series, definite femoral torsion was seen; in five no torsion was present; two were borderline. A total of sixty-seven derotational osteotomies were done in the

TABLE II

FINAL RESULTS AFTER TREATMENT

Type of Dislocation	Successful Results (92 Per cent.)			Unsuccessful Results (8 Per cent.)	Totals
	Normal	Near Normal	Satisfactory	Failures	
Primary posterior dislocation	19	18	20	4	61
Primary upward luxation or subluxation	7	4	4	2	17
Totals	26 (33%)	22 (28%)	24 (31%)	6 (8%)	78

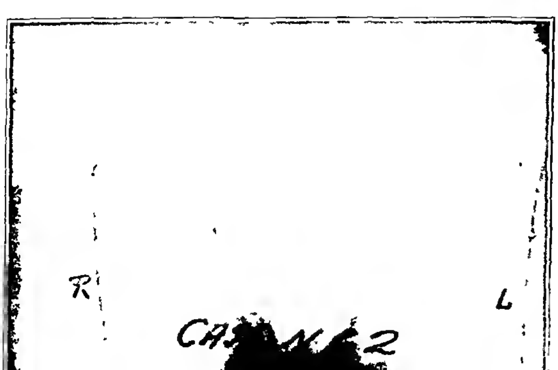


FIG. 13-A

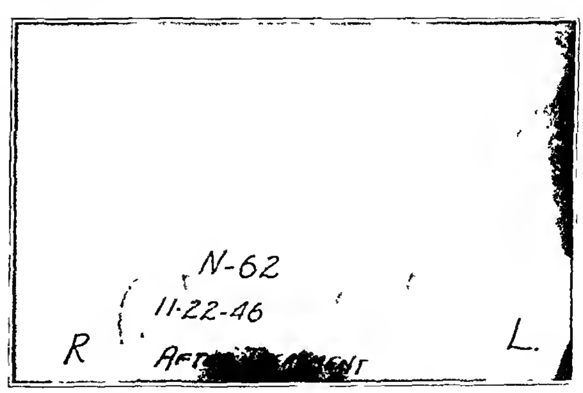


FIG. 13-B

N-62. Bilateral posterior dislocation. Treatment was begun at three years of age. Both hips were treated by preliminary skeletal traction, followed by derotational osteotomy. Nine years after treatment was begun, the results were graded as near normal, right, and normal, left.

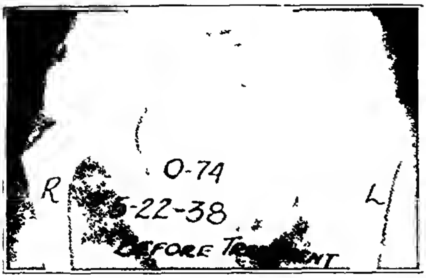


Fig. 14-A

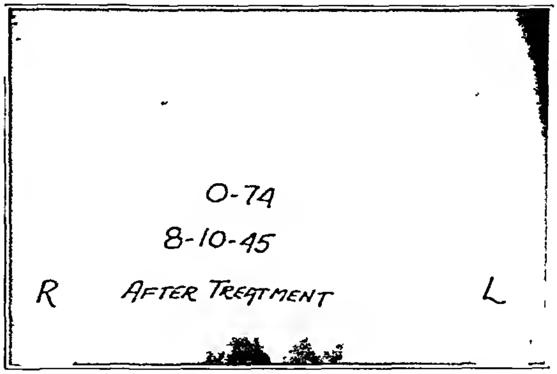


Fig. 14-B

O-74. Treatment was begun at two years of age, and consisted of skeletal traction and correction of bilateral torsion. The right hip became subluxated five years later, and acetabular reconstruction was performed. The results were finally graded as normal bilaterally, seven years after the beginning of treatment.

Fig. 15-A

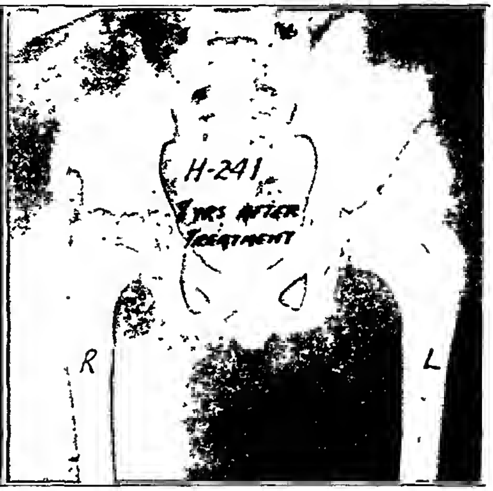


Fig. 15-B

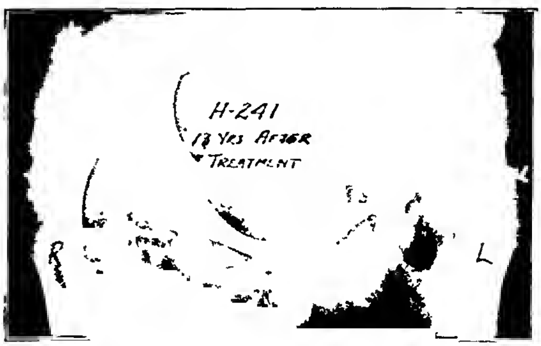


Fig. 15-C

H-241. Patient originally had bilateral posterior dislocation. He was treated on the right by skeletal traction, open reduction, and acetabular reconstruction; on the left, by skeletal traction and derotational osteotomy. Torsion on the right was purposely not corrected, to demonstrate that torsion does not correct itself. Five years after treatment the right hip was redislocated anteriorly, and the result was classified a failure. The left hip was classified as near normal. Since this present report was compiled, the patient has been seen again. At the present time both hips have redislocated, resulting in bilateral failure: this demonstrates that those cases which have not reached normal classification must be followed and treated, when indicated.

This failure will alter the results of treatment by increasing the number of failures by one and decreasing the number of near normals by one (Table II).

seventy-one hips showing torsion. Five of these osteotomies were done for the second time, because of incomplete correction of torsion by the first osteotomy.

After skeletal traction, closed reduction, and plaster immobilization in a position of reduction (abduction and internal rotation of the thigh) for three months, torsion is corrected by supracondylar osteotomy of the femur. Plaster fixation is maintained, with

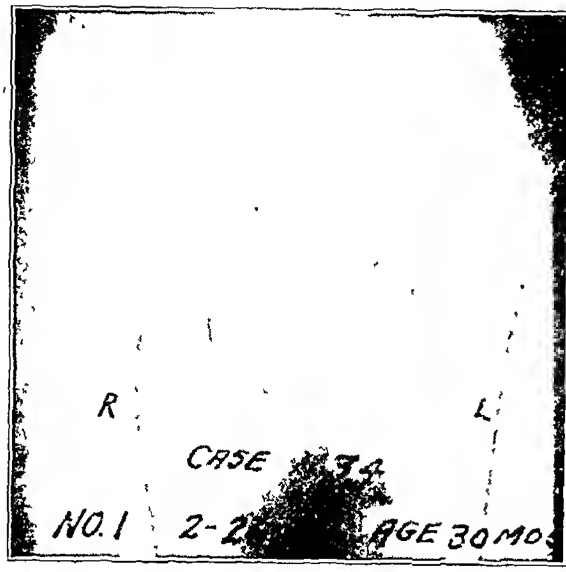


FIG. 16-A

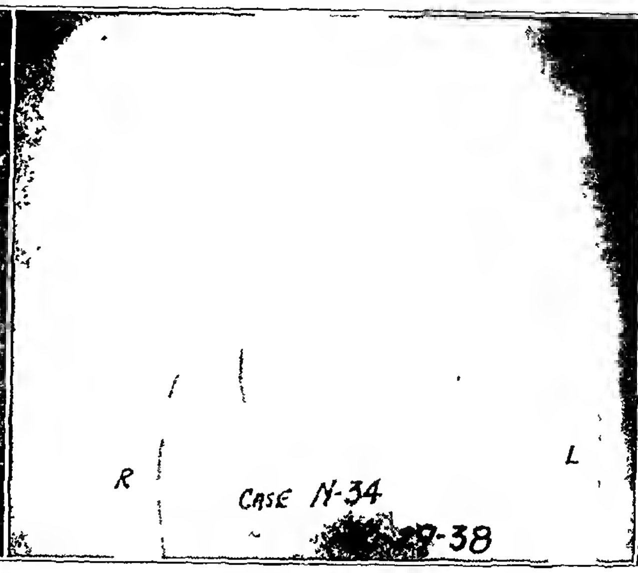


FIG. 16-B

N-34. Treatment, begun at three years of age, consisted of skeletal traction and derotational osteotomy. The result was graded as near normal, twelve years later. Fig. 16-B shows results one and one-half years after treatment; Fig. 16-C demonstrates improvement of appearance ten years later.

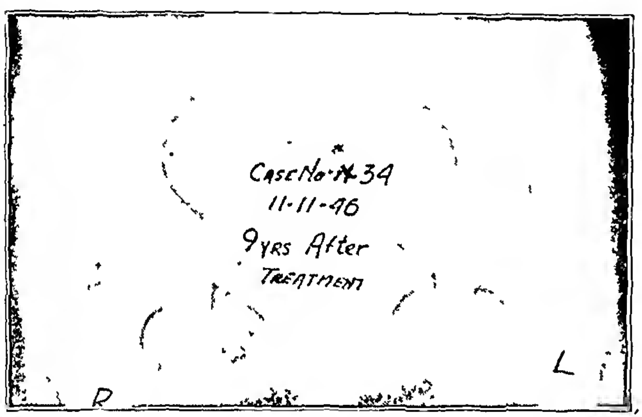


FIG. 16-C

the upper portion of the femur held in internal rotation, by incorporating a threaded wire through the bone just above the osteotomy site, while the knee and leg are rotated externally to neutral position. This position is held for two months longer, to allow the osteotomy to heal.

The effect of failure to correct torsion has already been reported. It is demonstrated in Figures 6-A and 6-B, in which torsion was purposely left uncorrected after an initial stable reduction of the hip, with the result that the head of the femur became redislocated into an anterior position.

Anomalies of the Capsule

It has been demonstrated repeatedly, as mentioned by Stewart, that the classic hourglass constriction, or invaginated fold of the joint capsule, may be interposed between the head of the femur and the acetabular fossa, thereby preventing satisfactory seating of the hip joint. After initial reduction, the head of the femur may stand out from the acetabular socket; yet in many instances, after three months' immobilization in plaster, the femoral head is found to be seated well and reduction is stable. This is probably the result of erosion of a capsular fold, or stretching of a partial constriction, which allows deeper seating of the joint.

In other cases it has been observed that, after initial traction sufficient to pull the head of the femur down opposite the acetabulum, the head can still not be seated into the socket sufficiently to maintain reduction. Open reduction of such dislocations after preliminary traction has revealed the capsular anomaly, and frequently the fossa is found to be filled with firm, fatty tissue and pannus, which hinder satisfactory seating of the head. Excision of the obstructing fold of capsule and the fatty tissue filling the acetabulum is indicated when the femoral head cannot be seated sufficiently to effect clinical stability at the time of reduction.

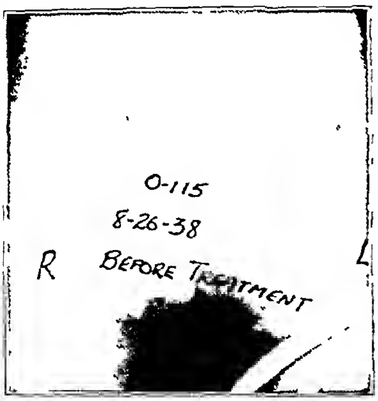


Fig. 17-A

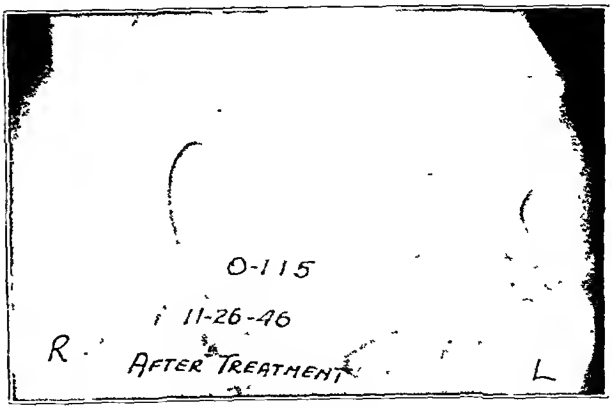


Fig. 17-B

O-115. Unilateral posterior dislocation. The patient was treated elsewhere at three years of age by manipulation and closed reduction. Redislocation occurred two and one-half years later. Treatment in this Clinic, at five and one-half years of age, consisted of skeletal traction, acetabular reconstruction, and derotational osteotomy. The result was graded as near normal, eight years later. Fig. 17-A shows appearance after reduction by skeletal traction. Original films were lost.

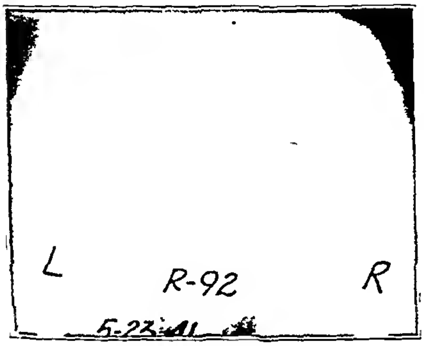


Fig. 18-A

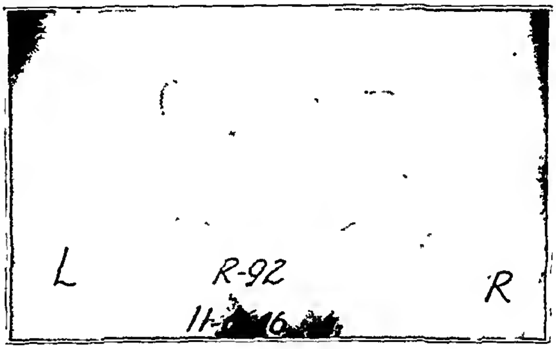


Fig. 18-B

R-92. Unilateral posterior dislocation. Treatment, begun at two years of age, consisted of skeletal traction, acetabular reconstruction, and derotational osteotomy. Result was graded as normal, five years later. (Roentgenograms have been reversed.)

After open reduction of the hip joint has been completed, the hip, in abduction and internal rotation, is immobilized in plaster-of-Paris for three months. After this, femoral torsion is corrected, if indicated. The plaster extends from the lower margin of the rib cage to include the toes on the affected side, and is carried down to the knee on the untreated side.

A total of twenty-five open reductions, for the purpose of relieving these obstructions to stable seating of the hip joint, have been done in this series.

Anomalies of the Acetabulum

Acetabular inadequacy of some degree is encountered in almost every instance of congenital dislocation of the hip. If the acetabulum, although shallow, is adequate to maintain initial reduction, it may eventually develop to the point where a well-deepened socket is formed. Nearly 50 per cent. of the hips studied followed this course.

In some of the hips treated it has been found that, after preliminary skeletal traction sufficient to allow placement of the head of the femur within the acetabulum, the head could not be held there in a stable manner, regardless of the position of the limb. Such hips are examined by fluoroscope; and, if the head of the femur can be placed into the acetabulum, yet in abduction and internal rotation a mild upward thrust of the femoral shaft causes the head to slip out of the socket, operative deepening of the acetabulum is indi-

cated. In these instances, acetabular reconstruction was performed during the initial treatment of the hip.

If, by fluoroscopic examination, the head of the femur could not be placed into the socket and stable reduction be effected, it was felt that open reduction was indicated. If, after excision of the interposed capsule and joint debris at open reduction, the reduction could not be maintained in a stable manner because of an inadequate socket, an acetabular reconstruction was then carried out. The operative deepening of the acetabulum, carried out in this series, has consisted in levering the superior acetabular rim down over the femoral head, and backing up this levered rim with cancellous-bone chips, taken from the wing of the ilium. The reconstruction is done as an extracapsular procedure (Fig. 7).

After acetabular reconstruction, the hip is immobilized in plaster, in a position of abduction and internal rotation, for a period of three months before any further treatment is carried out. After treatment has been completed in all phases, the plaster is removed and the hip is loosened up with the aid of physiotherapy. As soon after removal of the plaster as the patient is comfortable, active weight-bearing is begun. Occasionally a long thigh brace is applied for two or three months, if necessary, to protect a supracondylar osteotomy which is uniting slowly.

A total of forty acetabular reconstructions were required in this series of cases. Three of these were second reconstructions, the first operation having proved inadequate during

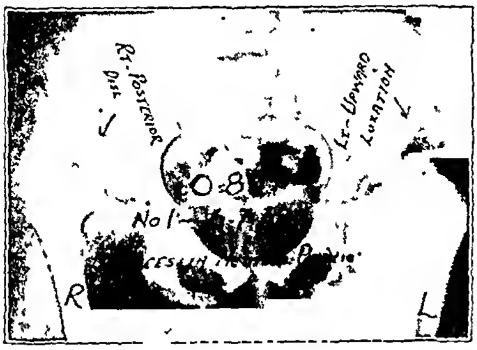


FIG. 19-A

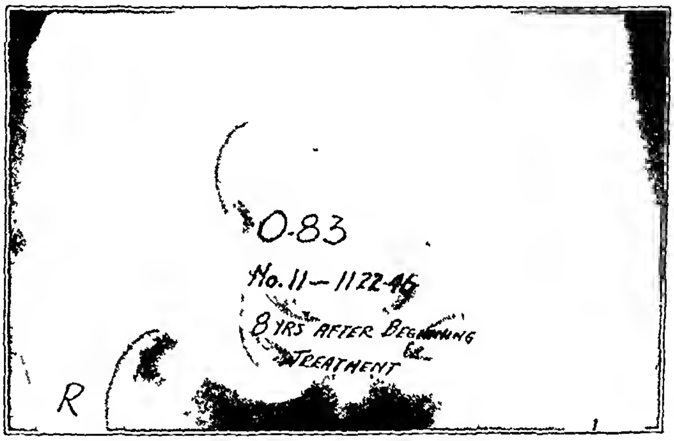


FIG. 19-B

O-83. Upward luxation, left; posterior dislocation, right. Treatment was begun at three years of age. The left hip was treated by skeletal traction, acetabular reconstruction, and derotational osteotomy. The right hip was treated by skeletal traction and derotational osteotomy at four years of age. Results were graded as normal, bilaterally, eight years after treatment was begun.

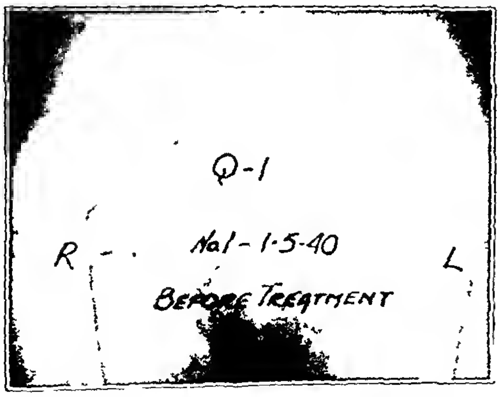


FIG. 20-A

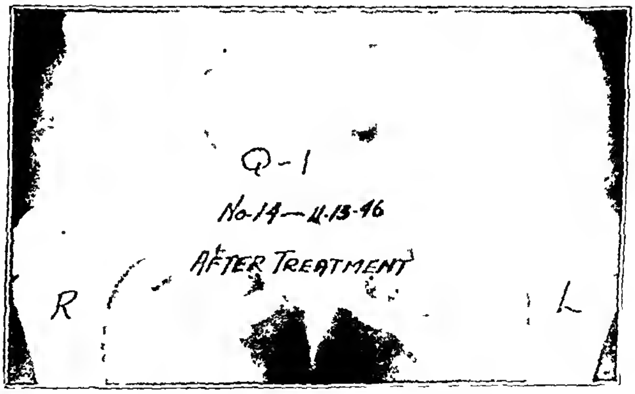
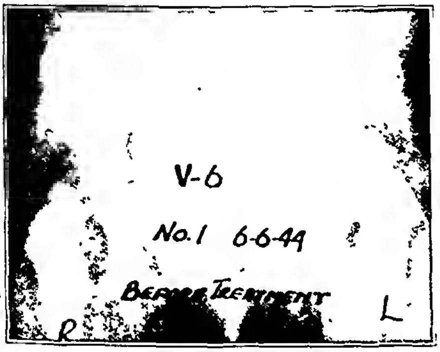


FIG. 20-B

Q-1. Bilateral upward luxation. Treatment was begun at five years of age. The left hip, treated by skeletal traction and derotational osteotomy, became redislocated three months later; it was then treated by skeletal traction and acetabular reconstruction. The right hip was treated by skeletal traction, acetabular reconstruction, and derotational osteotomy. Results were graded as normal bilaterally, six years later.

Fig. 21-A Fig. 21-B

Q-4. Unilateral upward luxation. Treated first at five years of age by skeletal traction and osteotomy. Redislocation occurred six months later, and treatment was again by skeletal traction and acetabular reconstruction. Results were graded as normal, six years later.



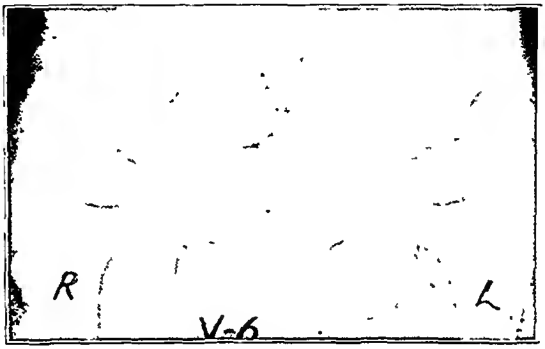


Fig. 22-A Fig. 22-B

V-6. Bilateral subluxation. Treatment was begun at two years of age. Both hips were treated simultaneously in wide abduction and internal rotation, by immobilization in long leg plasters, fixed by cross bars. Immobilization was continued for six months, and then derotational osteotomies were done (see Fig. 4). Results were graded as near normal, two years later.

the follow-up period. Three of the reconstructions were for recurrent dislocation to an anterior position, and have been termed "anterior buttresses". The anterior-buttress operation is described in McCarroll's report on the treatment of primary anterior dislocation of the hip.

In eight of ten hips classified as having primary upward luxation, acetabular reconstruction was required. One of the others will probably require reconstruction before treatment is completed. The remaining one is classified as normal after a follow-up of nine years; no operative work on the acetabulum is required. Of the seven cases classified as subluxation, acetabular reconstruction has been required in two. Thirty acetabular reconstructions have been required in the sixty-one cases of primary posterior dislocation.

The relatively high number of acetabular operations among the patients with upward luxation is explained by the fact that a notched defect of the superior acetabular rim is constantly present in this type of hip. and reconstruction is usually required before a stable reduction can be effected.

Gill states that acetabular operation should be delayed until the patient is five years of age. Such a requirement has not been met in the present series, and the results of acetabular operations done before five years of age (Table I) are not such as to contraindicate reconstructions prior to this age.

RESULTS OF TREATMENT

The results of treatment for this series of seventy-eight cases are analyzed in Table II. In order to compare the results from the method of treatment used in this series with

TABLE III

RESULTS ACCORDING TO LENGTH OF FOLLOW-UP

Results	1 Year	2 Years	3 Years	4 Years	5 Years	6 Years	7 Years	8 Years	9 Years	10 to 15 Years	Total
Normal..........	0	1	0	2	1	3	5	4	3	7	26
Near normal.....	0	5	2	2	0	3	1	0	2	7	22
Satisfactory......	3	7	4	3	3	1	0	0	0	3	24
Failures.........	0	1	1	0	0	0	1	2	0	1	6
Totals......... ..	3	14	7	7	4	7	7	6	5	18	78

TABLE IV

RESULTS FROM MANIPULATION OR PRELIMINARY TRACTION, WITH OR WITHOUT DEROTATION OSTEOTOMY

Normal		Near Normal		Satisfactory		Failures		Total Hips
No.	Per cent.	No.	Per cent.	No.	Per cent.	No.	Per cent.	
As the Initial Treatment								
15	33	11	24	6	14	13	29	45
As the Only Treatment								
15	45	11	33	6	19	1	3	33

the results from Gill's bloodless reduction, the criteria set forth by Gill for classification of the results of treatment have been observed critically. The results are graded according to the following classification:

1. *Normal*

This implies normal function of the hip, normal structural restoration of the joint, and complete freedom from symptoms (Figs. 6-A, 6-B, 9-A, and 9-B). Patients with normal results are considered cured, and require no further treatment. The qualifying factors for this classification are:

(a) Normal acetabular structure, either from developmental progress or from surgical reconstruction;

(b) Normal seating of the hip joint;

(c) Normal development of the femoral head;

(d) Normal femoral neck;

(e) Normal function.

2. *Near Normal*

This group includes those hips in which normal function has been restored, with complete freedom from symptoms after full activity; but roentgenographically, anatomical restoration has not quite reached normal (Figs. 9-A and 9-B). Minimal deficiencies in restoration of the acetabulum, head, or neck, and a little less than normal seating of the hip joint may be present on roentgenographic examination. Full correction of femoral torsion and full clinical stability are required. Most of the patients in this group are improving, and many of the hips are expected to become normal as the follow-up period

increases. Continued observation is required, however, and further treatment may be required in some instances. One patient required acetabular reconstruction seven years after initial reduction, and during most of the period of observation could have been classified as near normal; however, subluxation of the hip appeared after seven years. That hip is now graded as near normal.

3. *Satisfactory* (Figs. 8-A and 8-B)

(a) Anatomical restoration of the acetabulum is deficient by roentgenographic examination.

(b) Reduction of the dislocation is maintained, according to roentgenographic examination.

(c) Clinically, the hip is stable.

(d) Normal function is present, or sufficient function to allow full activity of the hip, with relief of symptoms.

(e) Residual deformities of the head and neck may be present, with roentgenographic evidence of mild arthritic changes in the joint.

In none of those hips treated by preliminary skeletal traction did aseptic necrosis of the femoral head develop following reduction. Residual deformity of the head, comparable to the flattening and broadening observed in Perthes' disease, was not observed. Such deformities have been observed in some hips, treated prior to 1933[1,2] by bloodless reduction.

4. *Failures* (Figs. 6-A and 6-B)

(a) Redislocation or subluxation has occurred.

(b) There is loss of a useful range of motion.

(c) Clinical instability of the hip is present, with symptoms of pain and fatigue.

We consider all those hips having a satisfactory, near normal, or normal classification to show successful results from treatment. A total of 92 per cent. were successful, as compared with 8 per cent. which were total failures (Table II).

In Table III the results are classified according to length of follow-up period. Observation of the increasing number of normal results as the follow-up period increases would indicate that this form of management will produce a greater proportion of normal and near-normal hips in future evaluations. Table III shows that 23 per cent. of the cases have been followed from ten to fifteen years, and that nearly 50 per cent. have been followed for six or more years.

The simplest method used in this series to obtain and maintain initial reduction has been the use of manipulation (as defined) or traction, with correction of femoral torsion when necessary. Those hips treated *initially* in this manner, and those having *only* this form of treatment, are analyzed in Table IV. In the cases in which this method of treatment failed when used initially, further treatment has been employed to correct other abnormalities; and the cases have been reclassified, after treatment was completed, according to the final result from all treatment.

In the present series, a total of twenty-one hips were treated for recurrent dislocation, following initial reduction. In four of the twenty-one, the hips had been treated elsewhere by bloodless reduction and the frog position, but redislocation had occurred when the patients were seen here for the first time. Of the twenty-one hips treated as recurrences after a first attempt at maintaining reduction, in only four has a second redislocation occurred. In three of the four treated for a third time, reduction has been maintained in a stable manner.

SUMMARY AND CONCLUSIONS

Seventy-eight congenital dislocations of the hip are reported, and the results of treatment are tabulated. Classification of the results has been particularly critical, the criteria

set forth by Gill being used as a guide; and an attempt has been made to compare the relative efficiency of the method of management carried out in this Clinic with that of bloodless reduction, characterized by forcible manipulation under anaesthesia and prolonged immobilization in the frog position. Twenty-two normal and near-normal hips are shown in Figures 10-A to 22-B, inclusive.

In comparing the results of treatment by forcible manipulation and prolonged fixation in plaster in the frog position with treatment as carried out in this Clinic, the authors believe that the former method is not sound and that its use is not justified in congenital dislocation of the hip which can be treated before seven years of age.

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THE END RESULTS OF EARLY TREATMENT OF CONGENITAL DISLOCATION OF THE HIP

With an Inquiry into the Factors that Determine the Result*

BY A. BRUCE GILL, M.D., PHILADELPHIA, PENNSYLVANIA

"Congenital dislocation" is not an exact term, inasmuch as it includes not only those dislocations which occur before or during birth, but also those which occur after birth. Furthermore, it does not include those congenital abnormalities of the hip which may never lead to dislocation, but which do prevent the development of a perfect hip joint. The factor common to all these conditions is a prenatal defect in the development of the structures of the hip, best called "congenital dysplasia of the hip".

Five years ago the author read a paper before this Association on the same subject[5]. For this present paper additional cases have been analyzed, the former cases have been reviewed and brought up to the present date as far as possible, and an attempt has been made to discover the factors that determine the end results. The condition known as predislocation of the hip has been studied in the author's cases to learn what relation it has to this subject.

* Read at the Annual Meeting of The American Orthopaedic Association, Hot Springs, Virginia, June 30, 1947.

GENERAL STATISTICS

Patients treated			289
Bilateral dislocations			78
Hips treated †			367
Female	78 35 per cent.		
Male	21 65 per cent.		
Right hip (single)	41 00 per cent.		
Left hip (single)	59 00 per cent.		
Bilateral	26 9 per cent.		
Bloodless reductions			
By author		193	
By other surgeons		51	
Irreducible by manipulation (before four years of age)		33 (13 75 per cent.)	
Inoperable (before four years of age) because of extreme deformities		14 (5 83 per cent.)	
Reducible by manipulation		80 42 per cent.	
Open operations			
Following bloodless reduction by author		63	
Following bloodless reduction by other surgeons		36	
Without history of preceding reduction		92	

END RESULTS OF BLOODLESS REDUCTION

One hundred and five cases have been selected for study. The dislocations were all reduced by the author, and the cases were followed for a sufficient length of time to determine the end results tabulated here. The cases discarded from this study were judged to have been under observation for an insufficient length of time, even though the dislocations were considered to be satisfactorily reduced when the patients were last seen. In a number of the discarded cases, the patients were last recorded as "cured and discharged". The end results recorded here should be studied in conjunction with those presented in a preceding paper[5]. Furthermore, in order to avoid reprinting of illustrations, reference will be made to some of the illustrations used in previous publications.

Number of hips treated by reduction		105
Open operation subsequent to reduction		52
Without subsequent operation		53
End results in hips treated by reduction without subsequent operation		
Perfect	17 (16 19 per cent. of 105 hips)	
Excellent	11 (10 48 per cent. of 105 hips)	
Satisfactory	15 (14 29 per cent of 105 hips)	
Failures	10	
	53	

The total number of failures was sixty-two, or 59.05 per cent of 105 hips.

The designation *perfect* means perfect function and perfect anatomy. *Excellent* means perfect function and almost perfect anatomy (Fig. 9-E in preceding paper[5]). *Satisfactory* means perfect function in spite of evident defects in anatomy, such as obliquity of the acetabular roof, flattening of the head, or moderate protrusion of the head beyond the acetabular roof; but without an upward migration of the head, which is the evidence of subluxation. Perfect function means the absence of all symptoms: fatigue, pain, limp, positive Trendelenburg sign. *Failure* means recurrence of luxation or subluxation.

The *perfect* hips have been under observation for the following lengths of time: one for three years; one for six years; two for seven years (bilateral); three for eight years; two for nine years (bilateral); two for ten years (bilateral); one for thirteen years (bilateral,—one perfect, one a failure); two for fourteen years; one for fifteen years; one for eighteen years (bilateral,—one perfect, one a failure); and one for thirty-one years (bilateral,—one perfect, one a failure).

† Many hips are not included in these groups because of insufficient or non-available records.

FIG. 1-A

FIG. 1-B

Fig. 1-A: H. T., a man, aged forty-two years (July 24, 1944), with subluxation of left hip. Patient had a bloodless reduction when two years old; has had increasing pain, fatigue, and disability during the past ten years. Negative Trendelenburg sign. (*Reproduced, by permission of Thomas Nelson and Sons, from Nelson Loose-Leaf Surgery, 1946.*)

Fig. 1-B: July 23, 1945, one year after shelf (buttress) operation, complete relief from symptoms had occurred. (*Reproduced, by permission of Thomas Nelson and Sons, from Nelson Loose-Leaf Surgery, 1946.*)

FIG. 1-C

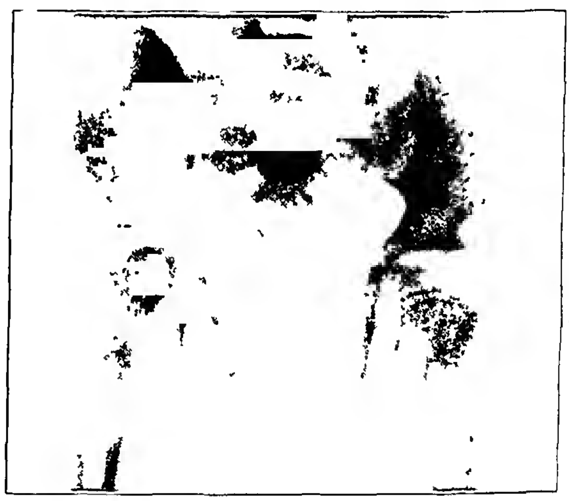

FIG. 2

Fig. 1-C: July 23, 1945 Showing freedom of abduction. (*Reproduced, by permission of Thomas Nelson and Sons, from Nelson Loose-Leaf Surgery, 1946.*)

Fig. 2: D. S., a girl August 8, 1946, seven years after reduction of bilateral dislocation (For history see Figs. 18-A, 18-B, 18-C, 18-D, and 18-E[5])

The time required after reduction for a hip to become perfect has varied greatly. Restoration of normal anatomy may be evident as early as three years, or it may be delayed until the age of puberty. (See Figs. 17-A to 18-E, 4-A to 4-E, and 6-A to 6-E in preceding paper[5].)

The *excellent* hips have been under observation for the following periods of time: one for three years (shows every indication of becoming perfect); two for four years; one for eight years; one for nine years; three for ten years; two for eleven years; and one for eighteen years. Eight of these eleven hips may almost be included in the classification of perfect. There is such slight departure from normal anatomy, it seems improbable that any symptoms would ever arise. Furthermore, it has been observed that some hips which earlier had been classified as excellent eventually became perfect. One of the cases under observation for ten years had become almost perfect three years after reduction, when a true Legg-Perthes disease developed which ruined the perfection of the hip (Figs. 19-A and 19-B[5]). The two cases which were under observation for four years cannot yet be classed as perfect, because insufficient time has passed.

Fig. 3-A

Fig. 3-B

Fig. 3-A: E. W., a girl, aged one year and eleven months (January 27, 1944). Patient had predislocation of left hip and dislocation of right hip. The dislocation was reduced by manipulation. (*Reproduced, by permission of Thomas Nelson and Sons, from Nelson Loose-Leaf Surgery, 1946*.)

Fig. 3-B: February 2, 1945, one year after bloodless reduction of right hip. Note the rapid development of acetabular roof and moderate dysplasia of epiphysis. (*Reproduced, by permission of Thomas Nelson and Sons, from Nelson Loose-Leaf Surgery, 1946*.)

If eight of the *excellent* cases were added to the seventeen proved *perfect* ones, the percentage of successful end results would be 23.81. If all eleven were added, the percentage would be 26.67.

It is, of course, possible that some of the fifteen *satisfactory* cases may become excellent or perfect, but these results have not been proved. It may safely be stated that, if a hip has not become excellent or perfect at puberty, it should be classed as a failure. If obliquity of the acetabular roof has not been corrected at this time, symptoms will develop in later years, because of instability and because of a chronic traumatic arthritis which is due to the anatomical abnormalities of the structures of the hip joint.

It is of interest to note the time after reduction at which the fifty-two operations were done because of luxation or subluxation: twelve, one year after reduction; nine, two years; nine, three years; three, four years; five, five years; two, six years; two, seven years; two, eight years; and eight, eleven to twenty years after reduction. This indicates that redislocation occurs most frequently during the first three years after reduction. Nature completely lacked the power to resume the delayed or interrupted normal growth of the hip in these cases. In many of the patients operated upon in the later years, Nature was able to accomplish partial restoration of the hip to a varying degree, but the power of growth was never sufficient to produce a perfect hip. Eight patients were symptom-free for from eleven to twenty years (Figs. 14-A through 14-E[5]). The author operated upon one patient, not included in these cases, who had a subluxation and was free of symptoms for thirty years after reduction (Figs. 1-A, 1-B, and 1-C).

Whether a hip becomes perfect after reduction, whether there is a varying degree of growth short of the perfect, or whether there is complete failure in the resumption of development seems to depend upon some innate power of growth in the structures of the hip.

Ninety-nine hips, of patients whose ages were recorded, have been tabulated, to show the relation between the age of the patient at the time of reduction and the end result (Table I).

Of twenty-two hips in which reduction was carried out during the first and second years of life, 22.73 per cent. became perfect and 45.45 per cent. were failures. Of thirty-eight hips in which reduction was done during the third year of life, 21.05 per cent. became perfect and 44.74 per cent. were failures. There is a negligible difference in the percentages

Fig. 4-A

Fig. 4-A: N. D., a girl, aged three months (May 12, 1945). Shows subluxation of left hip. Both femoral heads are visible at this very early age. *(Reproduced, by permission of Thomas Nelson and Sons, from Nelson Loose-Leaf Surgery, 1946.)*

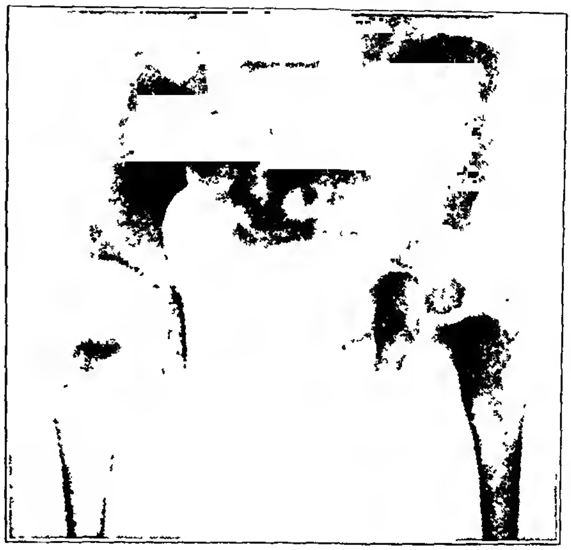

Fig. 4-B

Fig. 4-B: December 3, 1945. Hip has become normal in seven months. *(Reproduced, by permission of Thomas Nelson and Sons, from Nelson Loose-Leaf Surgery, 1946.)*

tabulated in the first two columns. Approximately 35 per cent. of hips treated by reduction during the first three years of life may be expected to become perfect or excellent. After the third year, however, there is a marked decrease in the percentage of successful reductions and a marked increase in the failures. The end of the third year marks a distinct turning point. To this limited extent only do these statistics lend support to the common opinion that the earlier a dislocation can be reduced, the better will be the end result. Successful reductions can be accomplished even after the child is four years of age.

TABLE I

RELATION OF END RESULTS TO AGE OF PATIENT AT REDUCTION

Results	Under 2 Years		Third Year		Fourth Year		Over 4 Years		No. of Hips
	No.	Per cent.	No.	Per cent.	No.	Per cent.	No.	Per cent.	
Perfect	5	22 73	8	21 05	2	10 53	2	10	17
Excellent	3	13 64	5	13 16	2	10 53	1	5	11
Satisfactory	4	18 18	8	21 05			1	5	13
Failure	10	45 45	17	44 74	15	78 95	16	80	58
Totals	22		38		19		20		99
Perfect and excellent	8	36 37	13	34 21	4	21 06	3	15	

It is generally conceived that the importance of the time factor—that is, the age of the child at the time of reduction—is due to the secondary pathological changes which occur in the anatomy of the hip after dislocation has occurred and which become more marked as time passes. It may be observed, however, that hips which become dislocated as late as the walking age may be more amenable to successful reduction than those which were dislocated at the time of birth or before. The age of the patient may not be the same as the age of the dislocation and, therefore, may not be a definite criterion of the secondary pathological changes in the hip; nor is it necessarily true that the age of the dislocation measures the *degree* and the *importance* of the anatomical changes. Otherwise, all hips of the same age should be similar in the ease of their reduction and in their renewal of growth after reduction. Actually, this is far from the fact.

FIG. 5-A

Fig. 5-A: J. T., a boy, aged two and one-half months (June 5, 1942), with predislocation of right hip. Note absence of calcification of femoral heads. *(Reproduced, by permission of Thomas Nelson and Sons, from Nelson Loose-Leaf Surgery, 1946.)*

Fig. 5-B: June 21, 1943, one year after beginning of treatment by abduction, the acetabulum is well developed. The epiphysis is just appearing, at fifteen months of age, and is smaller than that of the opposite hip. *(Reproduced, by permission of Thomas Nelson and Sons, from Nelson Loose-Leaf Surgery, 1946.)*

Fig. 5-C: October 17, 1944. The acetabulum is not yet perfect. Marked aplasia of femoral head is present. *(Reproduced, by permission of Thomas Nelson and Sons, from Nelson Loose-Leaf Surgery, 1946.)*

Fig. 5-D: January 3, 1947, four and one-half years after treatment was begun, acetabulum is normal. Right femoral head still shows some degree of aplasia.

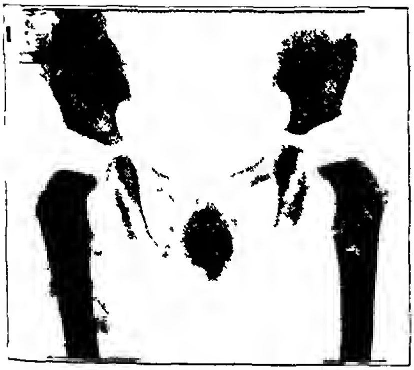

FIG. 5-B

FIG. 5-C

FIG. 5-D

FIG. 5-E

Fig. 5-E: June 13, 1947, five years after treatment was begun. Hip is almost normal, but the femoral head is slightly smaller than normal and protrudes moderately beyond the margin of the acetabulum. This case illustrates delayed growth of both acetabulum and femoral head in a case of predislocation.

If one considers that, in dysplasia of the hip, the acetabular development is weak and defective before dislocation occurs, one can understand that the length of time during which the head remains out of the socket may have an important bearing on resumption of growth of the acetabular roof. In other words, prolonged interruption of growth, occasioned by the absence of normal conjugation of the femur and the pelvis, may so weaken or destroy the natural growth process that it cannot effectively be restored. This conception of the time factor may be much more important than is the relation of this factor to the development of specific secondary pathological alterations in anatomy.

One-third of the hips in which reduction is performed in the first three years of life

become fully or almost normal; two-thirds do not. Some factor, more important than the time factor, is present in the determination of the end results of reduction. This is to be found in the form and the degree of the congenital dysplasia, which is caused by a retardation or by an interruption of normal growth processes. This is well illustrated in Figures 17-A through 18-E[5]. In Case 17 a unilateral dislocation was reduced when the child was three months of age. The femoral epiphyses were visible (smaller in the dislocated femur) at this early age. After reduction, growth was resumed at a rapid rate. At the end of eight months (Fig. 17-C) the hip was almost perfect, and at the end of three years (Fig. 17-D) it was completely normal in anatomy and function.

One might conclude that early reduction of the dislocation was the chief factor in the perfect result, but, in contrast, the case illustrated in Figures 18-A to 18-E shows bilateral dislocations which were not reduced until the child was eighteen months of age. Calcification of the femoral epiphyses was completely absent; the bony acetabula were poorly developed; and there was marked version of the femoral necks. Inspection of the roentgenograms might cause one to think that a perfect result could never be obtained. However, the subsequent films, made after reduction, show a resumption and rapid continuation of growth, which resulted in the development of perfect hips. The final result is shown in Figure 2 in this paper. The resumption and rapid continuation of growth in a dislocated hip, in which reduction was not obtained until the child was two years of age, is illustrated in Figures 3-A and 3-B.

These three cases, in which the dislocations were reduced at three months, eighteen months, and twenty-four months of age, respectively, in all of which the hips were perfect within three years after reduction, indicate that some innate power of growth which has survived delay or interruption is of much greater importance than the time factor in the production of a perfect hip. The other "perfect" hips in this same age group required a longer time, even to the age of puberty, to reach perfection; and, in two-thirds of the hips reduced within the same age period, the results were failures.

A study of predislocation of the hip is of particular value in an observation of the intrinsic and the relative importance of the two factors which determine the end result,—namely, the age at which treatment is begun and the residual and continuing power of normal growth processes.

Inasmuch as 94 per cent. of predislocations may be treated satisfactorily by abduction[6], it would seem at first glance that the time factor is of prime importance in the healing of congenital dysplasia of the hip. This matter will bear analysis, however.

At some time during either embryonal or foetal life, something happens that delays or alters normal morphogenesis of the hip. This etiological factor, whether it be genetic (hereditary) or mechanical, or due to a constitutional or physiological condition of the mother (for it seems possible that in different instances there may be different etiological factors), may exert a very slight or a very profound influence upon the morphological development of the structures of the hip joint. Abundant clinical evidence is available to indicate that many gradations exist between these two extremes. It is generally believed that the severe deformities arise during embryological or early foetal life, because of interruption, distortion, or cessation of normal growth processes. There is some evidence to indicate that the mild deformities may originate during later foetal life, after a normal morphogenesis has been established and is well advanced. It is well known that growing structures may readily be affected by adverse extrinsic conditions, such as mechanical forces and nutritional and biochemical deficiencies, and may suffer retardation and even structural change. Upon restoration of normal conditions, the growth process may continue in the natural way, to produce perfect structures.

If we can reasonably conceive that growth of the hip has been only mildly retarded, we can understand why, in many cases of pre-dislocation and some cases of frank dislocation, rapid and complete recovery may occur under favorable circumstances. If the

FIG. 6-A

FIG. 6-B

Fig. 6-A: J. P., a girl, aged four years (December 8, 1944). Dislocation of left hip and small, shallow, deformed acetabulum are present. Note the acetabulum which is an extension upward of the primary one, with small conical, incompletely calcified head and deformed neck. Two attempts at bloodless reduction failed. (An attempt two years earlier by another surgeon had failed.) The dislocation was reduced February 2, 1945, by open operation. (*Reproduced, by permission of Thomas Nelson and Sons, from Nelson Loose-Leaf Surgery, 1946.*)

Fig. 6-B: October 12, 1945, eight months after open operation, the dislocation remained reduced. The acetabular roof is developing. (*Reproduced, by permission of Thomas Nelson and Sons, from Nelson Loose-Leaf Surgery, 1946.*)

power of growth is more feeble, possibly due to a more prolonged delay or to some constitutional factor, then we can also understand why recovery is more prolonged or why it never becomes complete. The influence of a constitutional factor is illustrated in Case 18[5]. That there is a difference in the rate of recovery after the reduction of dislocations was noted in the early part of this paper and was demonstrated in the paper published in 1943. That a similar difference may occur in predislocations is evident from a study of Figures 4-A to 5-E, inclusive, in this paper. Incomplete recovery is apparent in those cases which have been called satisfactory after reduction and in which a perfect acetabular roof did not develop.

The predislocations probably constitute the largest number of that group in which the damage to the growth process has been slightest, and in which full recovery occurs, not only with a minimum of treatment, but even spontaneously. Scaglietti is of the opinion that dysplasia of the hip is always bilateral in the newborn; that spontaneous healing of predislocation occurs frequently, even beginning during the foetal period; and that spontaneous healing of congenital dislocation may be much more frequent than has been demonstrated to date. If his opinion that dysplasia is always bilateral is correct, it must follow that, in cases of unilateral dislocation, there has been a spontaneous healing of the dysplasia of the opposite hip. The author has observed this condition in a number of his patients. That he has not seen it in all cases may possibly be due to the fact that spontaneous healing had occurred before the child was first examined.

If these statements in regard to predislocations are correct, it would appear possible that the time factor has much less influence upon the recovery of predislocations than it does in dislocations. It may be that the high percentage of recovery in predislocations is not due to early treatment, but to the fact that the patients have suffered the least degree of prenatal damage.

The evidence, therefore, seems to the author to show that the chief and essential factors which determine the end result in dysplasia of the hip are the nature and degree of the primary alterations of normal morphogenesis, and the ability or inability of the growth processes to overcome, under favorable conditions, the primary damage. The time factor is of importance in that, by early adequate treatment, a normal mechanical stimulation is

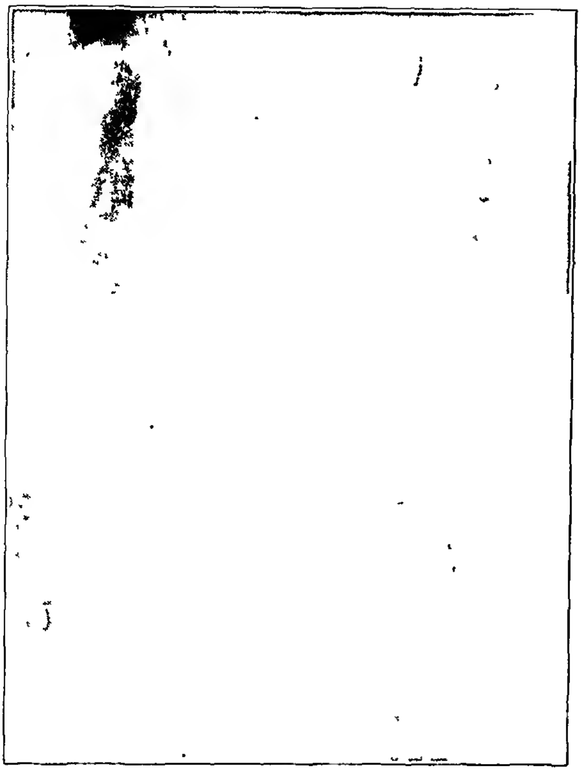

FIG. 7-A

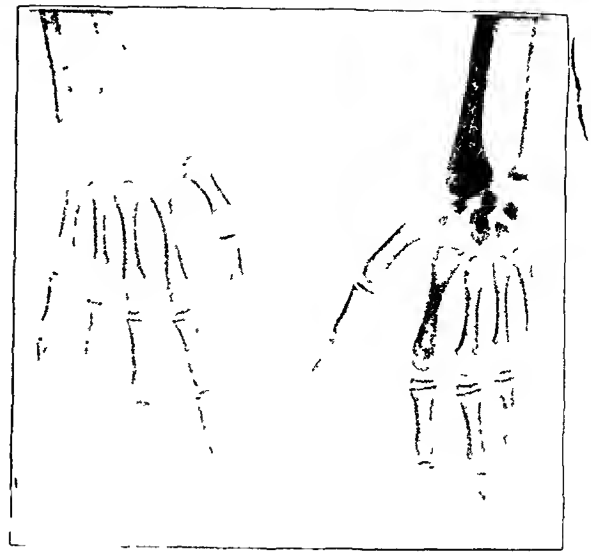

FIG. 7-B

R. T., a girl. May 14, 1932. Marked congenital deformities were present at birth: bilateral dislocation of hips, defect of right femur, and deformities of hands and feet.

provided for growth; but it is of no avail in the production of a "perfect" hip unless the primary factors are favorable to this end.

PRIMARY FACTORS THAT DETERMINE THE END RESULTS OF TREATMENT IN CONGENITAL DYSPLASIA OF THE HIP JOINT

Perfect and excellent end results can be obtained only in the predislocations and in those dislocations which can be reduced bloodlessly, because within these groups are those hips which have suffered the least primary damage and have the greatest residual power of growth. This statement does not mean that all predislocations and all dislocations amenable to bloodless reduction become perfect. It does mean, however, that, if open reduction must be done, the structural changes in the hip are of such a nature that a perfect hip cannot develop.

This broad assertion is based on the author's observations in the thirty-three cases (13.75 per cent.) in which the hips were operated upon before four years of age because they were irreducible by manipulation. No record of a "perfect" end result appears among them, although stability was obtained by operation in most of them and a useful amount of motion was achieved in many. These thirty-three operations, and the fifty-two which were performed because of failure of bloodless reduction, in the selected group of cases discussed in this paper and the many others tabulated, revealed the defects which make the development of a perfect hip impossible. Excluded from discussion are the 6 per cent. born with irremediable dislocations (see General Statistics) and the many old irreducible dislocations with marked secondary pathological deformities, in which the primary pathological condition could not be determined.

In a general way, the hips that *require* open reduction present the more serious defects. The thirty hips that were operated upon within three years after bloodless reduction had less marked defects, although some of them were of the same nature as those in the first group. The twenty-two cases in which operations had been performed from four to twenty years after reduction, which had been classed as satisfactory during these years, presented, for the most part, only the least serious defect,—namely, persistent aplasia of the acetabular roof, accompanied in a few cases by aplasia of the femoral head.

Let it be understood that the author does not deny, but, on the contrary, strongly affirms that satisfactory and even perfect *functional* results may be obtained by operative procedures for the correction of these various deformities of the hip[2-5]. The degree of improvement varies inversely with the degree of deformity, and even those with perfect function show some degree of anatomical imperfection (Figs. 12-A to 15-B, inclusive[4]).

Dysplasia, or probably better, *aplasia of the acetabular roof* is common to all predislocations and dislocations. If it is not associated with other structural defects of the hip joint, it offers the least obstacle to the production of a perfect hip. It appears to constitute the least departure from the normal morphogenesis of the hip. Under favorable mechanical conditions, Nature is able to develop a normal acetabulum quickly in most cases of predislocation, and more slowly in that smaller percentage of the cases of dislocation that achieve perfection. In addition, this defect of the hip, if it persists, is more easily and satisfactorily remedied by operative procedure than is any other defect. (See illustrations of shelf or buttress operation in Type I dislocations[2-5].)

Aplasia of the femoral head is manifested by delayed, irregular, or incomplete calcification, as seen in the roentgenograms. This condition was formerly, but erroneously, called Legg-Perthes disease, even by the author in some of his earlier papers. It can be observed in practically all cases of predislocation and dislocation. (See illustrations[5] and Figs. 4-A to 5-E, inclusive.) Nature may correct this condition early or late during the growth of the hip, as the acetabulum becomes perfect. The cotyloid and the epiphyseal growth appear to proceed *pari passu*. An unusual condition is illustrated in Figures 9-A, 9-B, and 9-C[4]. The bilateral dislocations were reduced bloodlessly when the child was seventeen months of age. The acetabula thereafter showed evidence of rapid growth that promised normal development, but the femoral heads showed no growth. At the end of five years the neck and head of each femur consisted of a round knoblike mass of bone, which lay beneath a fairly well-developed acetabular roof. This case indicates that dysplasia of the head may occur independently and prevent the formation of a perfect hip. Possibly in this case dysplasia of the head and of the femoral neck are bound together inseparably.

If the final result is a deformed socket, the head, if it remains within it, is similarly deformed. It has been noted by the author and by many other observers that the ligamentum teres, which carries a blood supply to the growing head, is frequently absent. Possibly its absence can account for the more marked cases of epiphyseal dysplasia, but it cannot explain the fact that *all* dislocations present the same dysplasia and that the dislocation becomes corrected as the acetabular dysplasia is corrected.

The opinion has been prevalent, and it still persists, that this aplasia of the head is due to excessive violence in manipulation during reduction. I do not deny that a soft head may be injured by such violence, and I even go as far as to prevent weight-bearing in cases of prolonged dysplasia (as in the treatment of true Legg-Perthes disease); but I cannot consider that this condition, which is a defect common to all dislocations both before and after reduction, is an evidence of excessive violence.

The *more severe deformities* of the structures of the hip joint, which prevent complete bloodless reduction and which, in the author's opinion, render the development of a perfect hip impossible, have often been enumerated. They consist chiefly of inequality in the size of the acetabulum and the head, deformities of the head, capsular constrictions, shortness of the neck, and, of great importance, high insertion of the capsule on the femur.

These pathological conditions and the surgical procedures adapted to their improvement have been described[2,3]. During the thirteen years subsequent to the last of these publications, the author has been impressed with the relatively high frequency of Type V (short neck and high attachment of the capsule) in children under four years of age who were operated upon because bloodless reduction was found to be impossible (Figs. 6-A and 6-B). While the operations described for these different conditions are very efficacious

in giving stability to the hip and in improving its function, yet not a single record shows the production of a "perfect" hip when any of the severe deformities were present.

Anteversion of the neck and *superior dislocation* (erroneously called "anterior dislocation") merit special discussion because of a difference of opinion as regards their nature and importance.

Many, if not all, dislocations present some degree of *anteversion*, although it is not always easy to prove this in the early roentgenograms. It has been the author's experience, as previously stated, that, if the dislocation can be reduced and the reduction maintained (fixation of the extremity in the position of internal rotation may be necessary in the more marked cases of anteversion), the normal growth processes in the reduced hip gradually bring about a correction of anteversion (Figs. 18-A to 18-E[5] and Fig. 2). More marked degrees of this condition may be found to accompany the serious deformities which make bloodless reduction impossible. This is particularly true in Type V (shortening of the femoral neck) (Figs. 6-A and 6-B). The shortening and the version are probably both due to the same pathological process. A rotation osteotomy will not serve to cure a dislocation, if other conditions are present to prevent it. Several cases have been seen in which one and even two osteotomies had been performed, with a final result of incurable dislocation. If primarily complete reduction was obtained in these hips, and if a rotation osteotomy of the shaft of the femur produces a complete and permanent compensatory correction of the anteversion of the neck, then some other condition must have caused the redislocation. Possibly the redislocation occurred because of a persistent aplasia of the acetabulum, the defect which can most easily and satisfactorily be corrected if taken in time; possibly it was due to one or more of the more serious deformities enumerated in a preceding paragraph. It is the author's opinion that the surgeon should not place his sole reliance on a compensatory rotation osteotomy of the femur, if defects other than anteversion are present in the hip; and, also, that other serious defects usually, if not always, accompany marked anteversion. A number of other orthopaedic surgeons do not agree with this opinion, and only continued observation by all will reveal the truth.

"Anterior" Congenital Dislocation of the Hip

It is accepted in surgical literature that, in an anterior dislocation of the hip, the head of the femur rests upon the anterior plane of the innominate bone, and in a posterior dislocation it rests upon the posterior plane. Nélaton's line marks the ridge or apex between these two planes[1]. In the congenital dislocations in question, the head of the femur lies below the anterior superior spine of the ilium, on the ridge between the two planes. It cannot slip forward upon the anterior plane and become a pubic dislocation, because of the firm attachment of the tensor fasciae femoris to the margin of the ilium, in the notch between the superior and inferior spines; and it never lies medial to the fascial plane between the tensor and the sartorius muscles. This type should be called a "superior" dislocation, because the head of the femur is directly above the center of the acetabulum in the weight-bearing position and it lies fully on neither plane of the pelvis. This condition is frequently accompanied by marked anteversion of the neck, which causes the head to become more prominent on the anterior aspect of the pelvis. Internal rotation of the femur may make the prominence of the head less apparent. I do not know why the head of the femur occupies this position. I am inclined to believe that morphologically this is a true posterior dislocation; that the head has emerged from the acetabulum in the weak spot of the cotyloid rim between the pubes and the ilium (in many roentgenograms one can observe a groove in this position); that the upward migration of the head is deflected by the straight head of the rectus femoris and by the main limb of the strong iliofemoral ligament, attached to the anterior inferior spine of the ilium; and that it thence pursues its upward course on the ilium in a position immediately posterior to its anterior margin, and comes to rest eventually beneath the anterior superior spine or slightly posterior to it.

This "superior" dislocation of the hip presents well-recognized difficulties in reduction and maintenance of reduction, owing chiefly to the marked aplasia of the cotyloid rim and the marked deformity of the neck. In my experience, open reduction, with the construction of an efficient acetabular roof by a properly performed shelf or buttress operation, is the only effective means of treatment. These hips can never become "perfect".

Finally, approximately 6 per cent. of all dislocations present such severe deformities that reduction by manipulation or open operation is impossible (Figs. 7-A and 7-B). Only some method of palliative operation may be available to reduce the amount of disability at a later time.

CONCLUSIONS

1. Approximately 25 per cent. of dislocated hips may be expected to become perfect or excellent after bloodless reduction. This percentage is increased to 35 in hips in which the dislocation is reduced during the first three years of life.

2. Another 15 per cent. of hips may be expected to become functionally satisfactory for a varying number of years, with the understanding that eventually symptoms of fatigue, pain, and limp may arise. This percentage is increased to 20 when the dislocation has been reduced before the end of the third year.

3. Failure (subluxation or recurrence of complete dislocation) may be expected in 60 per cent. of all primarily reducible dislocations, and in 45 per cent. of those reduced in the first three years.

4. The form and the degree of the dysplasia of the various structures of the hip joint which is present at birth, and the ability or inability of resumption and continuation of normal growth after reduction, are the essential factors that determine the end result.

5. The time factor (age of the child at time of reduction) is of secondary influence, inasmuch as the end results are better in hips in which the reduction was carried out during the first three years of life than in those reduced after this age. It is not this factor, however, which determines the result in the large group of hips in which reduction was achieved early. The high percentage of cures resulting from the treatment of predislocation seems to prove the great importance of the time factor; but this is open to question, because many cases of predislocation are cured spontaneously or by minimal treatment.

6. The "perfect" end results are to be found only among those cases that are amenable to bloodless reduction. If open operation is necessary for reduction, one can always observe the presence of one or more of those structural deformities that make the development of a perfect hip impossible. Of marked importance and frequency among these are the deformities of the neck of the femur and a high capsular attachment.

7. Various operative procedures are of great value to restore stability of the hip and to improve its function. Complete restoration of normal function and a close approach to normal anatomy may be obtained by a timely, wisely selected, and properly executed operation in cases of prolonged acetabular aplasia, unaccompanied by other, more serious deformities

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THE RESULTS OF TREATMENT OF CONGENITAL DISLOCATION OF THE HIP IN INFANCY*

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The normal development of the hip is dependent upon an intimate relation between the acetabulum and the head of the femur. In congenital dislocation of the hip, this relation is disturbed until the dislocation has been reduced. Long ago, Putti emphasized the importance of the early diagnosis and immediate reduction of the dislocated hip. Clinical experience, however, offers no definite assurance that early reduction will invariably bring about normal hip function. This review was undertaken for the purpose of exposing the reasons for the imperfect results among patients who had received treatment in early life for congenital dislocation of the hip.

The following analysis of the results of treatment of congenital dysplasia and of congenital dislocation of the hip is based upon a study of 112 such disorders, which occurred in eighty-six patients, upon whom treatment was commenced within the first three years of life. This analysis cannot be termed a study of the end results of treatment; rather it is a report of the early results, covering a period of from one to thirteen years after the commencement of treatment. The patients reviewed were unselected, and constitute all of those known to have been treated in two institutions and a private practice during a period of twenty-three years and one of fifteen years, respectively.

The accuracy of a report concerning the results of treatment is enhanced by the number of years during which the patient has been observed. A few of the infants reported have been observed for only one or two years; but, in the age group covered by this report, even this short period was considered sufficient to indicate the trend of development of the hip joints. However, the majority of the patients have been observed for from four to thirteen years following the treatment.

Throughout this report, the simple terminology for hip disorders suggested by Hart has been used. The types of disorders have, therefore, been designated either as dysplasia or as dislocation of the hip. The first term applies to those hips which lack normal development of the roof of the acetabulum, and the second designates those hips in which dysplasia is found in conjunction with some outward or upward displacement of the head of the femur. Such a simple classification seems entirely adequate to express the various degrees of displacement about the hip joint. No case of arthrogryposis has been included.

A review of the results obtained by treatment would be incomplete without some mention of the type of treatment employed. The patients included in this analysis were treated by a number of surgeons, and, therefore, the type of treatment has varied considerably. In general, however, the treatment of the past consisted of closed reduction by the method of Denucé. When the closed reduction or reductions failed, an open reduction, with or without reconstruction of the shelf of the acetabulum, was employed. In recent years, the original manipulation has been preceded by traction upon the extremity until the femoral head approached the level of the hip joint. The traction and abduction method of Putti, as modified by Coonse (Fig. 1-A), has usually been employed for

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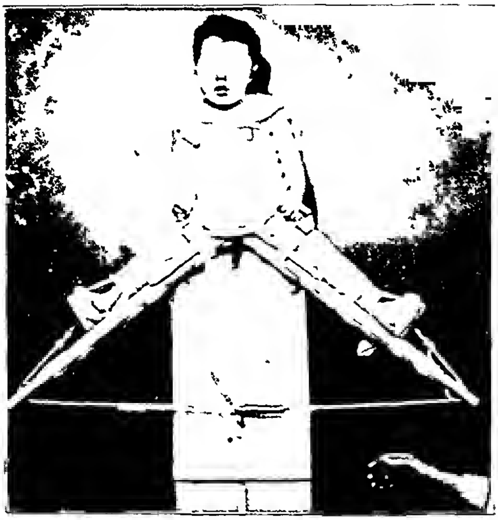

Fig. 1-A

Fig. 1-B

Fig. 1-A: Patient on a Coonse modification of a Putti frame.

Fig. 1-B: Same child on a Ponseti bar.

his purpose. Following traction, the head of the femur was simply rotated into the position in which it was most stable; although, in some instances, a more formal manipulation was also employed. An osteotomy to rotate the femur was used fifteen times upon the patients in this age group.

When plaster casts were used for fixation, the average period of such treatment was nine months. In the past two and one-half years the abduction bar described by Ponseti (Fig. 1-B) has been substituted for the plaster cast, approximately five months after reduction of the dislocated hip, for all patients observed within the first year of life and for many of those observed within the second year of life. Where some formal method of reduction was used, the treatment required a period of hospitalization. Treatment with the Ponseti bar, however, has been carried out by the parents at home. Some patients from the ages of one and one-half to three years have been treated for a short period in the hospital by traction on the Coonse frame, until reduction of the displacement had been effected. Immediately thereafter the Ponseti bar was substituted, so that a long period in the hospital was not necessary.

The authors' experiences do not permit definite conclusions concerning the age limits within which the Ponseti bar is effective; but when it has been employed in patients under the age of one and one-half years, no failures in effecting satisfactory reduction of the dislocation of the hip have resulted.

The abduction bar offers many advantages, in addition to elimination of the hospital stay. Among these is the complete mobility of the hip, permitted by the bar. Furthermore, the children have been taken out of the bar for one hour daily for the purpose of bathing and for unfettered exercise. While wearing the bar, the patients may crawl, climb, and stand. One disadvantage of the abduction bar is the forced position of genu valgum which follows wide abduction of the legs, but this has proved transient, as evidenced by the absence of permanent deformity of the knees after final removal of the bar.

METHOD OF ANALYSIS

A review of the literature indicates a lack of uniformity in the methods used to record the results of treatment for congenital dislocation of the hip. It is, therefore, difficult to make comparisons of the results reported in the medical literature. In 1941, Severin reported an end-result study in which he used a clear and concise method of expressing both the anatomical and the functional results which occurred after the treatment of congenital dislocation of the hip. In the opinion of the authors, when the effects of treat-

ment are to be reported, the classification of Severin, as modified by Ponseti, is worthy of general adoption.

These classifications of the anatomical and the functional results, which have been adopted for the present report, are as follows:

Anatomical Results (Severin)

Group I Normal hips;
Group II Moderate deformity of the femoral head or neck or acetabulum, but otherwise normal conditions in the joint;
Group III Dysplastic hips without subluxation;
Group IV Subluxation;
Group V The head articulating with a secondary acetabulum in the upper part of the original acetabulum;
Group VI Redislocation.

Functional Results (Ponseti)

Group I No symptoms;
Group II Slight pain in the hip on excessive walking;
Group III Limp, free motion, and no pain;
Group IV Limp and limitation of motion, but no pain;
Group V Limp and pain;
Group VI Limp, limitation of motion, and pain.

The term "subluxation," used by Severin to designate Group IV, is not particularly objectionable since, by its placement in the classification, it is obviously used to describe moderate degrees of outward, or outward and upward, dislocation of the head of the femur. The authors of the present report have ventured to add a Group I-A to Ponseti's classification of the functional results, in order to include a previously unseparated number of patients who show slight restriction of motion, even though they have no symptoms to suggest that the hip joint is imperfect.

Roentgenography is the sole means by which the anatomical condition of the hip may be judged. The interpretation of the roentgenograms should include specific in-

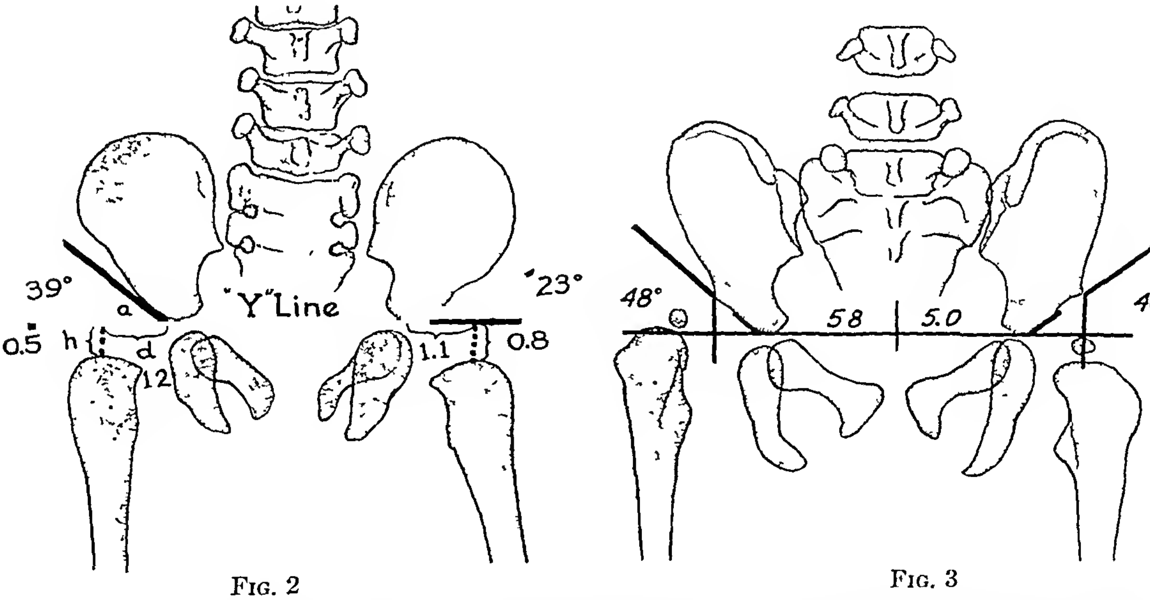

FIG. 2 FIG. 3

Fig. 2: Hilgenreiner's measurement. *a*, The acetabular index, *h*, the position of the diaphysis, measured from its most proximal shadow to the Y line, *d*, the distance from the most proximal shadow of the diaphysis to the acetabular floor.

Fig. 3: Unilateral dislocation at age of one year. Shows the acetabular index, Perkins perpendicular line from the upper and outer border of the acetabulum, and the Y coordinate

TABLE I

Congenital Hip Disorders Observed in Eighty-six Patients

Age at Reduction	Dysplasia Unilateral	Dysplasia Bilateral	Dislocation Unilateral	Dislocation Bilateral	Total Cases
First year	4	0	9	4	17
Second year	7	0	39	12	58
Third year	1	0	22	14	37
Totals	12	0	70	30	112

formation concerning both the acetabulum and the head and neck of the femur, as well as their relation to one another. The measurements of Hilgenreiner, as reported by Severin, satisfy these requirements, and they have been used in the interpretation of the roentgenograms which were surveyed in this study. In this measurement (Fig. 2) the transverse or Y line extends between the tips of the ilia at the region of the triradiate cartilage. The slope of the acetabulum is measured from the tip of the ilium to the upper and outer portion of the acetabulum. The angle between the line marking the roof of the acetabulum and the Y line has been aptly designated by Kleinberg and Lieberman as the "acetabular index" (Fig. 2). A third line, drawn perpendicularly from the Y line to the highest point of the upper femoral diaphysis, permits the measurement of the distance of the femoral diaphysis either downward or upward from the Y line, and also its distance outward from the tip of the ilium at the base of the acetabulum. The measurement of Perkins (Fig. 3), which is a perpendicular line from the upper and outer border of the acetabulum to the Y line, is also helpful in indicating the position of the head of the femur.

The Y coordinate for the hip joint has also been recorded upon the roentgenograms reviewed in this study. This is the measurement from the line of gravity of the body, as represented by a longitudinal line through the mid-sacrum, to the center of the head of the femur. Attention has been directed to the importance of this measurement by Ponseti, in his analysis of the results after the shelf operation for congenital dislocation of the hip. He observed a direct relation between an abnormal separation of the center of motion of the hip joint from the line of gravity and a poor functional result.

The authors have made numerous unsuccessful attempts to find an accurate method for recording the anteversion of the neck of the femur, and have also recorded various other measurements which have not proved helpful in this analysis.

The interpretation of measurements made upon the roentgenograms may be both difficult and misleading. If comparisons are to be made. a standard technique must be employed and the roentgen tube must be well centered over the pelvis, which has been

TABLE II

Position of Head of Femur in Reference to Y Line

	First Year (*Centimeters*)	Second Year (*Centimeters*)	Third Year (*Centimeters*)
Unilateral dislocation (Average level)			
Normal hip	−0.6	−0.52	−0.45
Dislocated hip	−0.23	+0.55	+1.0
Average displacement	0 37	1.07	1.45
Bilateral dislocation	+0.55	+0.93	+1.1

TABLE III

MEASUREMENTS OF "NORMAL" ACETABULA IN PATIENTS WITH UNILATERAL DISLOCATION

	High (*Degrees*)	Low (*Degrees*)	Average (*Degrees*)
First year (10 hips)	27.5	15	23.6
Second year (40 hips)	26	9	20
Third year (10 hips)	24	9	18.5

placed in a symmetrical position with the knees together and the patellae uppermost. When any doubt exists concerning the hip joint, the roentgenograms should be repeated at intervals. While the mathematical accuracy of the interpretation of the roentgenograms may be open to question, nevertheless the comparison of the two hips and of roentgenograms taken in series provides relative accuracy upon which a judgment may be based.

The evaluation of the functional results has either been based upon a personal examination by one of the authors, or has been taken from the records of the other orthopaedic surgeons who examined the patient.

ANALYSIS

Age of Patients at Time of Treatment

Of the 112 disorders of the hip which were reviewed in this analysis, seventeen or 15 per cent. were in patients treated under the age of one year; fifty-eight or 52 per cent. in the second year of life; and thirty-seven or 33 per cent. in the third year of life (Table I). The ages at which the diagnosis of dysplasia or dislocation of the hip was established range from eight days to thirty months. The records indicate that treatment of the dislocation was often not considered of an urgent nature, as evidenced by its postponement for a number of months after diagnosis. An indication of the increased awareness of dislocation of the hip is the fact that, in recent years, a greater number of infants have been referred for treatment. In this group of patients the urgency of the treatment has been thoroughly recognized.

TABLE IV

ACETABULAR INDEX IN 112 HIPS *

Age Group in which Treatment Was Started	No. of Months Required for Acetabular Index to Reach 27.5 Degrees or Less									Cases in which Acetabular Index Did not Reach 27.5 Degrees at Last Examination	
	6	9	12	15	18	24	30	36	More than 36	Observed Less than 36 months	Observed More than 36 months
First year	4	2	5	1	2					2	0
Second year		3	10 **	2	2	5	3	2	3 †	14	12
Third year			3	2			3	2	6	4	17

* In three hips the acetabular index was less than 27.5 degrees at start.

** One followed operation. † Two followed operation.

TABLE V

DEVELOPMENT OF ACETABULUM AND FEMORAL HEAD FOLLOWING THE TREATMENT OF CONGENITAL HIP DISORDERS

Type of Treatment	No. of Cases	Acetabular Index Remaining above 27.5 Degrees	Aseptic Necrosis
bduction frame	32	6	4
'raction and manipulation	13	9	7
Ianipulation without traction	31	7	23
:emanipulation	8	7	6
Iultiple manipulations (three or more)	3	2	2
pen reductions with or without shelf operation	21	16	16
helf operation only	2	2	1
o treatment	2	0	0

'ypes of Displacement

Dislocation occurred in 100 instances; in fifteen patients it was bilateral (thirty ips). There was a definite relation between the degree of displacement of the hip and the ge of the patient, as shown in Table II.

Dysplasia without dislocation of the head of the femur was present in twelve hips; in leven of these, it was accompanied by dislocation of the opposite hip. In this series, the bsence of other instances of dysplasia, either unilateral or bilateral, is difficult to explain, particularly since a careful search of the records has been made. The apparent discrepancy between this study and other reports may lie in the fact that the authors have considered even a moderate degree of displacement of the head of the femur as constituting a dislocation of the hip, rather than a dysplasia with subluxation. Nevertheless, the authors feel that adequate justification for using the simple classification of Hart lies in the fact that there was rarely agreement between them or among several roentgenologists as to whether a particular roentgenogram showed dysplasia with subluxation or dislocation of the hip.

Development of the Hip Joint as Revealed by Roentgenograms

The interpretation of the roentgenograms may furnish only relative, and not absolute, information concerning the hip joint. Roentgenograms taken with the lower extremities externally rotated and abducted and with the pelvis rotated backward present an entirely different acetabular index than those taken with the extremities together and the patellae uppermost. In roentgenography, therefore, a uniform method must be adopted, if comparison is to be made of the measurements of the anatomical relations of the hip joint.

a. The Acetabular Index

It is difficult to make any definite statement concerning the normal measurements of the acetabular index at various ages. Kleinberg and Lieberman reported that an acetabular angle of 27.5 degrees was normal for newborn infants. They also found an average angle of 20 degrees in their study of the roentgenograms of infants between one and two years of age. Measurements of a small number of normal hips, made by the authors, show a great variation of the acetabular index for infants in the first three years. These measurements ranged from a low of 12 degrees in a baby of four months to a high of 28 degrees in a child of one year. Further, in a review of the literature, no information

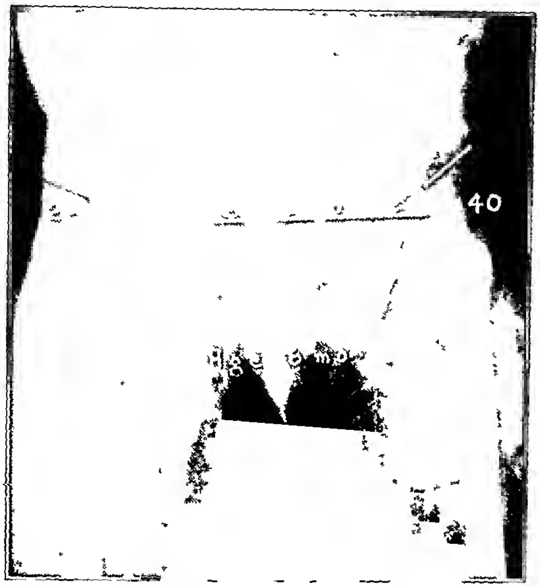

Fig. 4-A

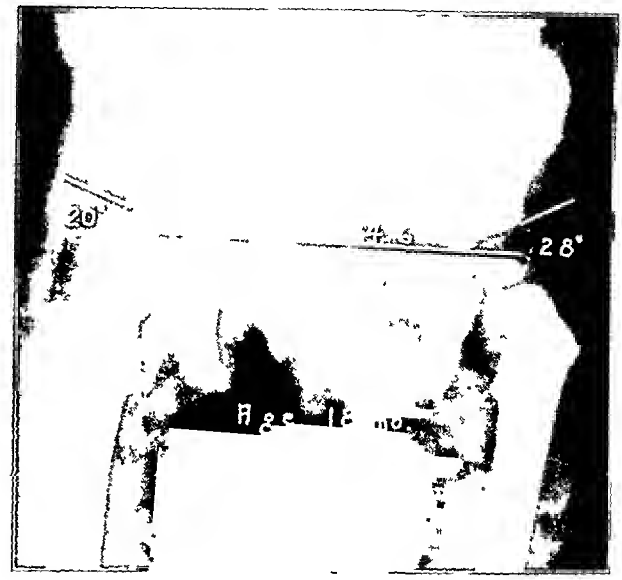

Fig. 4-B

Fig. 4-A: J. A. Unilateral dislocation in infant, aged six months.
Fig. 4-B: At age of eighteen months, after twelve months on Ponseti bar, differences between the acetabular index and the Y coordinate are much less.

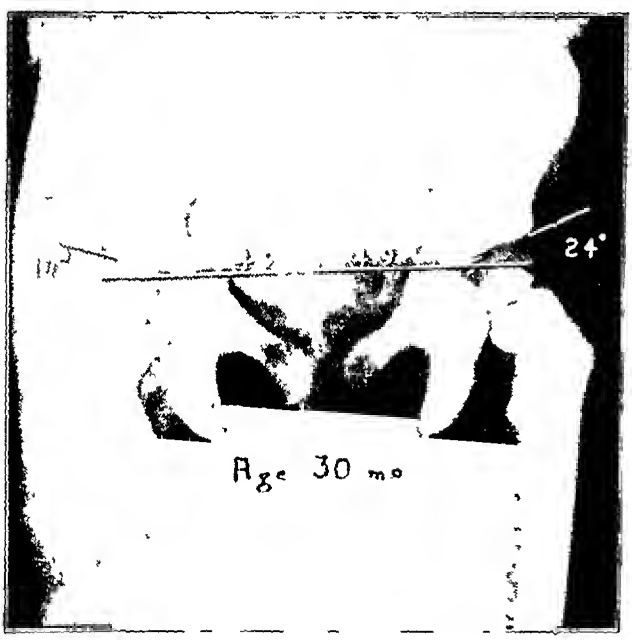

Fig. 4-C

At age of thirty months, after twenty-three months on a Ponseti bar. The Y coordinates are now equal and the left acetabular index is within normal limits.

could be found pertaining either to the rate or to the degree of descent of the acetabular index for each year of life.

In the dysplasias and dislocations reviewed in this report, the acetabular index of the abnormal hip varied from 27.5 to 55 degrees. Most of the hip joints, however, showed an acetabular index measuring from 30 to 40 degrees at the time of the first examination. For the patients who had unilateral dislocation, without dysplasia of the opposite hip, the measurements of the so-called "normal" acetabulum are shown in Table III.

In the present analysis, 27.5 degrees was selected arbitrarily as a fair estimate of the upper limit of the normal acetabular index in infancy. The time required for the acetabular index to reach 27.5 degrees or less was recorded for each of the hips in this series. As indicated in Table IV, in fifty-one hips (45.5 per cent.) the acetabular index dropped to 27.5 degrees within a period of three years, while nine hips (8 per cent.) required more than three years to reach that limit. In twenty-nine hips (25.9 per cent.) which were observed for a period of from three to thirteen years, the acetabular index failed to drop to the angle of 27.5 degrees. In twenty hips (17.9 per cent.) the index had not dropped to 27.5 degrees at the time of the last examination. These patients were observed for a period of from one to just under three years. In three hips (2.7 per cent.) a dislocation occurred, even though the acetabular index was at all times less than 27.5 degrees.

The time required for the descent of the acetabular roof (Figs. 4-A, 4-B, and 4-C) is of interest when viewed in relation to the age at which treatment of the dislocation was begun. Of the patients treated within the first year of life, all but two showed descent of the

TABLE VI

DIFFERENCE BETWEEN Y COORDINATE OF DISLOCATED AND NORMAL HIP

Treatment Started	No Difference	Less than 0.5 Centimeter	0.5 to 1.0 Centimeter	Over 1.0 Centimeter	Total Cases
First year	4	6		1 *	11
Second year	7	12	15	4	38
Third year	3	5	3	11	22
Totals	14	23	18	16	71

* After operation.

acetabular index within a period of eighteen months. These two patients had been observed for only one year, at the end of which the acetabular index had not yet reached 27.5 degrees. In those patients treated during the second and the third years, the descent of the acetabular index appeared more gradual than during the first year, and, in nearly one-half of the patients, never dropped as low as 27.5 degrees. A survey of the fifty-one hips showing a drop to 27.5 degrees or less within three years revealed that many approached the acetabular index of the normal, undislocated hip, but that only six actually reached that acetabular index.

In an attempt to determine the response of the acetabulum to the various types of treatment, the hips under review were segregated, according to the method of reduction which had been employed (Table V). The roof of the acetabulum failed to drop to 27.5 degrees in thirteen (20 per cent.) of the sixty-three hips which were treated either by abduction or by a single manipulation. The same failure was noted in nine (70 per cent.) of thirteen hips which were subjected to traction and manipulation, and in twenty-seven (80 per cent.) of thirty-four hips in which operation or repeated manipulations were required to bring about a reduction. These data might easily be misinterpreted, since the traction, the remanipulations, and the operations were usually employed in the older patients, or in those upon whom the simple methods had failed. Moreover, the simple

TABLE VII

Y COORDINATE OF FINAL ROENTGENOGRAM IN CASES OF BILATERAL DISLOCATION

Age at Beginning of Treatment (*Months*)	Right Hip		Left Hip		Difference (*Centimeters*)
	Y Coordinate (*Centimeters*)	Group	Y Coordinate (*Centimeters*)	Group	
29	8 3	V	7 8	V	0.5
33	9 3	II	9 9	II	0 6
24	9 0	IV	7 1	IV	1.9
32	6 7	I-A	6 4	I-A	0 3
15	7 9	I-A	9 3	I-A	1 4
19	5 9	I	6 5	I-A	0 6
3	5 0	I	5 0	I	0
34	7 5	IV	8 5	IV	1 0
29	8 4	IV	5 9	IV	2 5
24	8 4	I-A	7 8	I-A	0 6
6	5 7	I	5 7	I	0
24	10 5	VI	9 5	VI	1 0
30	9 0	IV	7 5	IV	1 5
24	5 6	I	5 6	I	0
30	6 0	I	6 0	I	0

TABLE VIII

DIFFERENCE BETWEEN Y COORDINATE OF DISLOCATED AND NORMAL HIP

Functional Results	No Difference	Less than 0.5 Centimeter	0.5 to 1.0 Centimeter	Over 1.0 Centimeter	Total Cases
Group I No symptoms	12	21	15	0	48
Group I-A Slight limitation of motion; no symptoms	1	0	1	4	6
Group II Slight pain	0	0	0	0	0
Group III Limp, free motion, and no pain	0	2	2	3	7
Group IV Limp, limitation of motion, but no pain	1	0	0	8	9
Group V Limp and pain	0	0	0	0	0
Group VI Limp, limitation of motion, and pain	0	0	0	1	1
Totals	14	23	18	16	71

methods were more commonly applied to the younger patients with the least deformity, and, therefore, those in whom the acetabulum was in a more plastic state. Nevertheless, it may be concluded that the development of the acetabulum was the greatest in those patients upon whom the least traumatic methods were employed.

b. The Y Coordinate

The Y coordinate was measured on all of the earliest and on all of the latest roentgenograms of the hips included in the study. In the earliest films, this measurement was helpful in determining the amount of displacement of the head of the femur. When the head of the femur had not yet ossified, the distance was measured from the mid-line to

FIG. 5-A

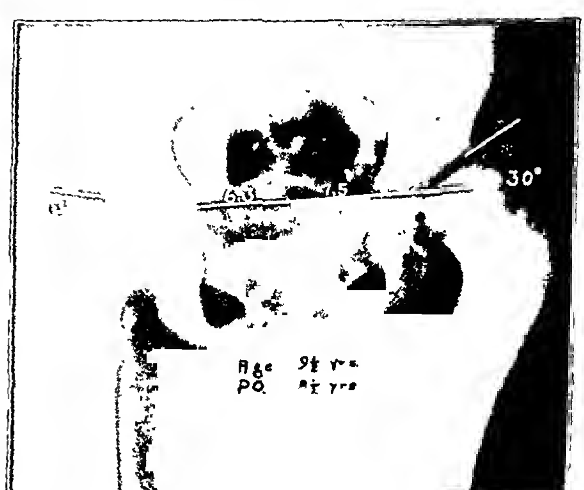

FIG. 5-B

Fig. 5-A: Child aged three years; one year after operation. The left femoral head is not well seated in the acetabulum.

Fig. 5-B: At age of nine and one-half years; a rotation osteotomy has been done. The left femoral head is still not well seated.

TABLE IX

ANATOMICAL RESULTS IN RELATION TO AGE AT WHICH TREATMENT WAS STARTED

Anatomical Results (Severin's Classification)	First Year		Second Year		Third Year		Total	Per cent.
	Dysplasia	Dislocation	Dysplasia	Dislocation	Dysplasia	Dislocation		
Group I Normal hips	2*	8	3	7			20	17.9
Group II Moderate deformity of head, neck, or acetabulum, but otherwise normal	2	4	4	20		12	42	37.5
Group III Dysplastic hips without subluxation				18	1**	10	29	25.9
Group IV Subluxation				2		1	3	2.6
Group V Head articulating with secondary acetabulum in upper part of original acetabulum				3		11	14	12.5
Group VI Redislocation		1		1		2	4	3.6
Totals	4	13	7	51	1	36	112	100.0

*One case was untreated.

**This case was untreated.

the highest point on the diaphysis of each femur. Whenever ossification of the head of the femur was apparent, the measurement was made in the usual manner. Outward displacement of the head of the femur, which increases the Y coordinate, may be caused by a thickening of the bony floor of the acetabulum, by soft tissues interposed between the acetabulum and the head of the femur, by a maladaptation between the size of the head of the femur and of the acetabulum, or by an enlargement of the head of the femur (Figs. 5-A and 5-B).

From the final films of the seventy-one unilateral dislocations, in which the opposite hip was normal, measurements of the Y coordinate were made for the three age groups (Table VI). The measurements indicate that the institution of treatment in early life has an important effect upon the adaptation of the femur to the acetabulum.

Of the fifteen patients who had bilateral dislocation of the hip, the Y coordinate was rarely the same for each hip (Table VII). In the eleven dysplastic hips the Y coordinate was, of course, always less than that of the dislocated hip on the opposite side. In the seventy-one cases of unilateral dislocation, the Y coordinate was also compared with the functional result (Table VIII).

With one exception, all of the patients with an increase in the Y coordinate of less than one centimeter had good functional results. The exception was a boy whose hip had been treated unsuccessfully by an open reduction before he was twelve months old. Reduction was achieved by a closed manipulation, but thereafter the hip remained quite stiff. In four patients of Group III, the Y coordinate showed an increase of less than one centimeter as compared with the normal side. Re-examination of these patients showed that they had good functional results, in spite of the elongation of the Y coordi-

TABLE X

ANATOMICAL RESULTS IN RELATION TO METHOD OF TREATMENT

Anatomical Results (Severin's Classification)	Abduction Frame	Traction and Manipulation	Manipulation	Remanipulation	Multiple Manipulations *	Open Reduction with or without Shelf Operation	Shelf Operation Only	No Treatment	Total
Group I	12	1	6					1	20
Group II	18	6	12	3	1	2			42
Group III	2	4	9	3	1	8	1	1	29
Group IV		1	1			1			3
Group V		1	3	1	1	7	1		14
Group VI				1		3			4
Totals	32	13	31	8	3	21	2	2	112

* Three or more manipulations.

nate. Among the hips with an increase in the Y coordinate of over one centimeter are four which can be classified in Group I-A; the others are in the groupings which designate imperfect function of the hip. In the bilateral dislocations (Table VII), the Y coordinate was determined for each hip. With one exception, where the Y coordinate was less than seven centimeters, all of the hips which were measured were placed in functional Groups I, II, or III. The one exception was the unstable hip in which the Y coordinate measured

TABLE XI

THE FUNCTIONAL RESULTS IN RELATION TO AGE AT WHICH TREATMENT WAS STARTED

Functional Results (Ponseti's Classification, Modified)	First Year		Second Year		Third Year		Total	Per cent.
	Dysplasia	Dislocation	Dysplasia	Dislocation	Dysplasia	Dislocation		
Group I No symptoms.	4*	12	7	34	1*	10	68	60.7
Group I-A No symptoms; slight limitation of motion. .				9		4	13	11.6
Group II Slight pain in the hip on excessive walking. .						2	2	1.8
Group III Limp, free motion, and no pain.				2		5	7	6.3
Group IV Limp and limitation of motion, but no pain. . .		1**		4		12	17	15.2
Group V Limp and pain.						2	2	1.8
Group VI Limp, limitation of motion, and pain.				2		1	3	2.6
Totals	4	13	7	51	1	36	112	100.0

*One case was untreated.

**Operated upon elsewhere at 8 months of age.

TABLE XII

FUNCTIONAL RESULTS IN RELATION TO METHOD OF TREATMENT

Functional Results (Ponseti's Classification, Modified)	Abduction Frame	Traction and Manipulation	Manipulation	Remanipulation	Multiple Manipulations*	Open Reduction with or without Shelf Operation	Shelf Operation Only	No Treatment	Total
Group I............	32	9	18	2	1	4		2	68
Group I-A............		3	5	2	1	1	1		13
Group II............			2						2
Group III............			1	2		4			7
Group IV............		1	5	1	1	8	1		17
Group V............						[illegible]			2
Group VI..........				1		2			3
Totals............	32	13	31	8	3	21	2	2	112

*Three or more manipulations.

5.9 centimeters. On the other hand, where the Y coordinate was over seven centimeters, most of the hips were placed in functional Groups IV, V, or VI. Two patients were placed in Group I-A in spite of Y coordinates of over seven centimeters. Both of these patients had moderate stiffness, which may explain the stability of the hips in question. One of the patients, with a Y coordinate of 9.3 centimeters on one side and 9.9 centimeters on the other side, was placed in Group II; and perhaps this rating is open to some question. In some of the patients with bilateral dislocation of the hip, it was noted that, in spite of a considerable difference in the measurements of the two hips, the functional results were reported as similar. It was not possible to re-examine all of these patients.

c. The Head of the Femur

In the younger patients, a delay in the ossification of the head of the femur was invariably present. This delay in development continued over a period of two or three years. In most instances, irregularities in the ossification and in the shape of the head of the femur appeared throughout the period of observation. Some of these irregularities were apparently caused by pressure from the impingement of the head of the femur against the rim of the acetabulum.

The development of the size and shape of the head of the femur was followed with interest. In the roentgenograms of some of the hips, the head of the femur appeared too

TABLE XIII

ANATOMICAL RESULTS COMPARED WITH FUNCTIONAL RESULTS

Anatomical Results	Functional Results: Group I	Group I-A	Group II	Group III	Group IV	Group V	Group VI
Group I	19	1					
Group II	34	3	2	2	1		
Group III	15	8		2	3		1
Group IV		1		1	1		
Group V				1	10	2	1
Group VI.				1	2		1

large for the acetabulum. A great number became somewhat oval in shape or flattened, rather than assuming the characteristic spherical contour of the head of the normal femur.

d. Aseptic Necrosis

Aseptic necrosis was observed during or after the course of treatment in fifty-nine hips, or 52 per cent. of the total series (Table V). Of this number, the distribution, according to the age at which treatment was started, was as follows:

Year	*No. of Cases*	*Aseptic Necrosis (No.)*	*Aseptic Necrosis (Per Cent.)*
First	17	2	12
Second	58	34	59
Third	37	23	62

The relation of the type of treatment to aseptic necrosis is noted in Table V. This indicates that aseptic necrosis developed in only 12 per cent. of the hips treated by abduction, whereas the incidence of aseptic necrosis was 54 per cent. and 74 per cent., respectively, in the hips that required reduction by traction and manipulation or by manipulation alone. Undoubtedly, the age of the patient at the time of treatment also had an important bearing upon the incidence of aseptic necrosis, since the least traumatic methods were used in the younger infants.

RESULTS

Anatomical Results

With the exception of the one hip in which a redislocation occurred, all of the hips in which treatment was started within the first year are placed in Groups I and II (Table IX). In the second year, approximately one-half of the hips are in these groups, while dysplasia of the acetabulum (Group III) occurs frequently. No hips in which treatment was delayed until the third year appear in Group I; only one-third of the hips appear in Group II, and the other two-thirds are distributed,—about half in Group III and the rest in those groups which designate a poor anatomical result.

It is well known that deterioration in the anatomical results may be expected with increasing age. This fact must be considered in the interpretation of the results noted in this report, since many of the patients have been observed for a short period only and few of them have reached the fourteenth year.

The anatomical results have also been tabulated with respect to the type of treatment employed (Table X); it may be seen that the majority of the hips treated by simple methods appear in Groups I, II, and III. The age of the patient, of course, has influenced the method used in effecting reduction of the hip.

Functional Results

Seventy-four per cent. of the 112 hips were placed in Groups I, II, and III, which represent hips showing excellent function. With the one exception noted previously, the hips of all patients in whom treatment was started in the first year appear in Group I (Table XI). Most of the hips treated in the second year responded favorably to treatment. Less than half of the patients treated in the third year are in the group of good results.

The functional results (Table XII) were also compared with the method of treatment which had been used. The greatest number of good functional results appeared among those who had received treatment of the least traumatic types. Practically all of the poor functional results occurred in those hips which had required either repeated manipulations or reduction by operation.

Comparison of Anatomical and Functional Results

Table XIII shows that all of the hips with normal anatomical ratings have excellent function, and that most of the hips with moderate anatomical deformity show excellent

functional results. It is also noteworthy that, among the dysplastic hips which were followed throughout the years of childhood, there was little or no disturbance of function. As might be expected, the poor functional results were in those hips which showed the greatest deviations from normal anatomical growth and development.

COMMENT

The authors do not wish to present any positive conclusions from the statistical analysis given here, but an attempt has been made to interpret the data included in this study. It is unfortunate that all of the patients could not have been examined by the authors, and that none could be followed into adult life. Nevertheless, it is to be hoped that some useful deductions may be drawn from this analysis.

The case histories indicate that both signs and symptoms of dysplasia and of dislocation of the hip were usually present, and were often recognized by the parents and the physician long before the diagnosis was established. These signs and symptoms were: the flexed and externally rotated hip, the increased thigh folds, the apparent shortening of the thigh, the "clicking" hip, the prominence of the trochanter and the head of the femur, the limitation of abduction, and the limp. The records also show that the importance of treating the dislocation or dysplasia is still not properly appreciated by members of the medical profession. In the present series, the absence of patients with simple dysplasia of the hip serves to emphasize the need for a more careful examination of the infant. Many such patients must have been overlooked and, while it is known that some dysplasias and dislocations undergo spontaneous recovery, it is certain that many such hips fail to develop normally.

The increased amount of displacement of the dislocated hip with each successive year of infancy lends support to the present theories concerning postnatal dislocation of the hip.

The difficulties attendant upon the interpretation of roentgenograms of the hip in the infant have been mentioned. These difficulties call for the adoption of standards for making the roentgen exposures, and for the collection of further information in reference to the growth and development of the infant hip joint.

In this study, the measurement of the roof appeared to be a reliable index of the growth of the acetabulum. After reduction of the dislocation, or in dysplasia, a wide abduction of the femur was followed by growth of the roof of the acetabulum. This is probably due to removal of the pressure of the femur from the rim of the acetabulum, as well as to the restoration of the normal pressure of the head of the femur in the hip joint. From a study of the hips in this series, there seems little doubt concerning the effect of reduction of the head of the femur in early infancy. Both the rate and the amount of growth of the acetabulum appear favored by a reduction performed in early life, before the occurrence of overgrowth and maldevelopment of the hip. With the advance of each year of infancy, the chance of securing a normal hip appears proportionately decreased.

Measurement of the Y coordinate gave definite information in relation to both the diagnosis and the effects of treatment of congenital dislocation of the hip. In the unilateral dislocations, an increased Y coordinate indicated that anatomical maldevelopment was present. In the measurements of the final roentgenograms, it was noticed that the Y coordinate approached the normal much more frequently in the hips having early treatment than in those in which the treatment had been delayed. As in Ponseti's study, a rather definite correlation was found between the Y coordinate for the hip and the function of the hip. In the unilateral dislocations, an increase of one centimeter over the normal gave rise to a disturbance of function. In the bilateral dislocations in this series, a Y coordinate greater than seven centimeters usually denoted a hip with poor function. The results of a maladaptation between the acetabulum and the head of the femur were evidenced by changes in the shape and size of the head of the femur. A number of the changes in the shape were the result of aseptic necrosis.

The present analysis indicates that both the postponement of treatment and the trauma at the time of reduction of the hip influence the incidence of aseptic necrosis of the head of the femur. The influence of the age of the patient upon the anatomical and functional results is seen throughout this analysis. The earliest treatment brought about the best growth and development of the hip and, therefore, was followed by the best functional results. Also, as mentioned previously, the simple, atraumatic methods may be employed with success in the treatment of young infants, thereby eliminating the complications which may follow the trauma of forced or repeated manipulations and the treatment by operation.

In the final analysis, it is apparent that age is the most important factor influencing the results of treatment of congenital dislocation of the hip.

SUMMARY

1. The standards of Severin and Ponseti have been used in an evaluation of the anatomical and functional results of treatment in 112 cases of dysplasia and dislocation of the hip.

2. Excellent or nearly excellent anatomical results were obtained in 55.4 per cent.; and 60.7 per cent. of the functional results were excellent. Deterioration with age would not be expected in this group. The best results were noted when the treatment used was the least traumatic.

3. Good anatomical results were produced by treatment in infancy in 81.3 per cent., and good functional results in 80.4 per cent., of the hips examined. The temporary nature of these results is not disputed, since all of the patients were less than fourteen years of age when the ratings were made.

4. The development of the acetabulum progressed slowly, indicating a probable need for longer periods of fixation after reduction of the hip. Delay in reduction of dislocations causes increasing maldevelopment of the hip, due in part to a thickening of the acetabular floor coincident with an increase in the Y coordinate. These factors are of importance in treatment and prognosis.

5. There is a direct relation between the early institution of treatment and the good results reported.

6. Even with an early diagnosis and an early application of treatment, the results of the treatment of congenital dislocation of the hip in infancy are far from perfect. Great effort must, therefore, be directed toward both earlier recognition of the dislocation and improvement of the present methods of treatment.

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,ONE CHANGES IN THE CAT IN EXPERIMENTALLY PRODUCED INJURY TO THE PERIPHERAL NERVES *

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S. Weir Mitchell quoted the findings of Packard, in 1863, on arthropathies of the foot nd knee, following compression of the sciatic nerve by a tumor. Since that time, a num- er of cases of neuropathies of the bones and joints have been reported, following peri- heral-nerve injury and disease. Mitchell described a case in which extensive joint lesions eveloped after an injury to the brachial plexus, due to a dislocation of the shoulder.

The earlier reports dealt chiefly with simple atrophy of bone, which was attributed o disease and to changes in the joints. Among reports of atrophy of bone were the cases een by Blum, Ogle, and Arnozan; these are mentioned by Bowlby, who, however, had not een such cases himself and concluded that they were rare. Hirsch described a case of trophy of the bone, resulting from injury to the median nerve. Goldscheider mentioned case of atrophy of the bones of the hand, following disease of the ulnar nerve. A number f cases were described by Maliwa and by Lehmann.

Mitchell stated further that wounds or any lesions of nerves may produce inflammatory onditions in the joints, usually subacute, which so precisely resemble rheumatic arthritis n their symptoms and results that no clinical skill can discriminate between the two. Arthritic changes were referred to by McArdle, who described them as occurring when a nerve trunk was pierced, rubbed, or lacerated, but not when a peripheral nerve was severed, unless the nerve ends became bulbous or were caught in healing tissue. The opin- ion of that day was well expressed by Turney, who stated: "It is fairly certain that di- vision of a nerve *per se* does not produce changes in the bone, except in so far as it causes paralysis. It is the partial division of nerves resulting in prolonged irritation that is the effective cause, and this, as we have seen, may be brought about by interference in any part of the reflex arc." With some intuition he said: "Had *x*-rays been available Weir Mitchell would undoubtedly have completed his account of 'glossy skin' by a description of the accompanying atrophy of bone".

Some years before, Sudeck had described an acute atrophy of bone, associated with inflammatory processes in the articulations, which he later called post-traumatic reflex atrophy of bone. About the same time, Kienböch added to the clinical findings and gave a description of the roentgenographic changes. This type of osteoporosis is most frequently found in the short bones of the hands and feet; next in order of frequency are the epiphyses of the metatarsals, metacarpals, and phalanges, and then the epiphyses of the long bones.

Although, because of concomitant injuries, such cases of osteoporosis have been consid- ered as associated with peripheral-nerve injuries, they are not the consequence of injuries of large nerves or trunks. In the material of Herrmann, Reineke, and Caldwell, in which reports from a number of clinics are reviewed, it apparently was not found that peripheral- nerve injury, as apart from general, often minor, trauma, played a part.

In some cases, the disproportion between the severity of the pain complained of and the minor character of the trauma, or trauma at a distance, in addition to the changes in the mental attitude of the patient, led to a diagnosis of hysteria. Simons described cases in which, along with "psychogenic paralysis and contractures", similar osteoporosis was seen. In these cases the association of vasomotor, secretory, and other trophic changes in the skin and muscles indicated their identity with the cases of so-called physiopathic

* The work described in this paper was done under a contract recommended by the Committee on Medical Research, between the Office of Scientific Research and Development and Northwestern University.

reflex-nerve disturbances, reported by Babinski and Froment. Here there was a difference of opinion: Some, including Babinski and Froment, insisted upon an organic origin; others, as Roussy and Lhermitte, maintained that the basis was hysterical. In the author's experimental work, no such conditions have been encountered.

Numerous cases of bone and joint disturbances associated with lesions of the peripheral nerves were observed during World War I. In addition to types similar to those described by Sudeck and Kienböch, there were also reports of acute osteoporosis; simple atrophy of bone, usually attributed to disuse; and changes resembling chronic articular rheumatism,—some in cases of painful lesions of the median and tibial nerves, and some in joints, underlying infection and ulcers. Maliwa mentioned a number of cases of atrophy of the bones of the hand, associated with lesions of the ulnar and median nerves, as contrasted to the cases described by Simons.

Simple atrophy was said by Lehmann [11] to be rare in the adult. However, he reported[10] six cases of atrophy in the bones of the hands, and also two cases of atrophy in the calcaneus after injury to the sciatic nerve. Changes resembling chronic articular rheumatism or arthritis deformans were observed by a number of authors, quoted by Bumke and Foerster. Sterling mentioned particularl the type associated with mal perforant, callus formation, microchiria, micropodia, and macropodia. These are of rare occurrence and, according to Lehmann, are always associated with ulceration and infection. For the most part, the greater proportion of instances of changes in bones and joints were associated with partial and usually painful lesions. Their common occurrence in causalgia is noted by Benisty. On the other hand, complete lesions of large trunks of nerves, uncomplicated by vascular or other injuries, infection, or ulceration, were rarely found in association with bone atrophy.

The author was unable to find any recent reports of experiments to determine the effect of denervation upon adult bone. Howell and Tower have described the relation of neural influences upon bone growth and development. For experiments dealing with atrophy of adult bone, one must consult some very old reports, and the conclusions are by no means clear or in agreement. In the often quoted experiments of Schiff, the bones of the paralyzed limb were less voluminous than those on the opposite side, whereas the periosteum of the paralyzed side was thickened. Two months after the operation had been performed on two cats, although the bones were smaller, the medullary cavities were large. Schiff concluded that the immobility of muscles produces atrophy of bone. He found, however, when animals were allowed to survive twelve or eighteen months, that many parts of the bone were thicker than on the normal side.

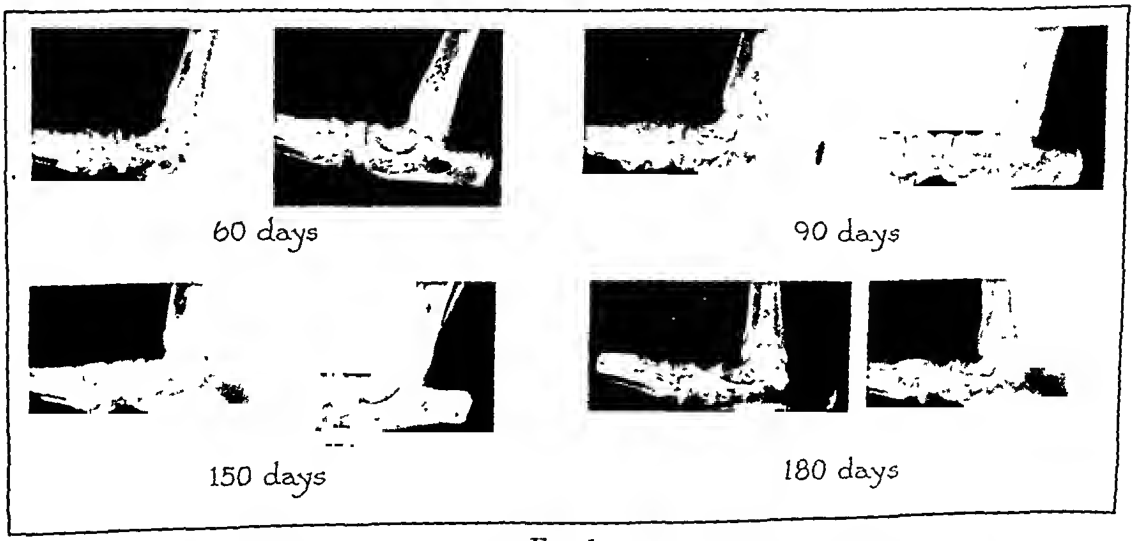

Fig. 1

Roentgenograms illustrate appearance of bones in animals at various times after primary suture

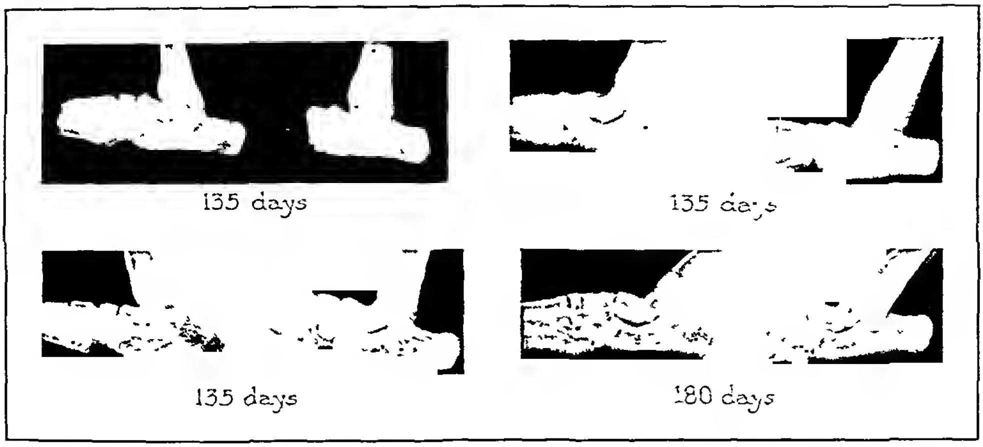

FIG. 2
Roentgenograms taken at various intervals after secondary suture.

Ogle refers to a monograph of Luigi Fasce and Domenico Amato, who, in 1866, stated that a constant reduction of weight took place in the bones of paralyzed limbs after the division of nerves. Ogle also cites Palermo, who, after dividing the brachial plexus of the rabbit, found no changes in the bone.

An experiment upon the effect of electrotherapy on muscle atrophy in cats made available to the author a considerable number of extremities in which denervation had been performed by section of the sciatic nerve, about four centimeters below the sciatic notch. The material may be divided into three groups: first, the animals in which no ulcers developed, either after primary suture or after secondary suture sixty days following section or denervation; second, the animals in which ulcers appeared at some time after surgery; and third, a group of animals whose denervated extremities were immobilized in plaster casts.

In twenty-seven animals, ulcers did not develop after section alone, or section and primary or secondary suture; none showed any changes in the bones which could be demonstrated by roentgenogram. In this group there were twelve animals in which primary suture followed section of the nerve: Three were x-rayed at 60 days, five at 90 days, three at 150 days, and one at 180 days after operation. In addition, there were three animals in which secondary suture followed sixty days after section of the nerve: Two were x-rayed at 135 days and one at 180 days. Finally, there were twelve denervated

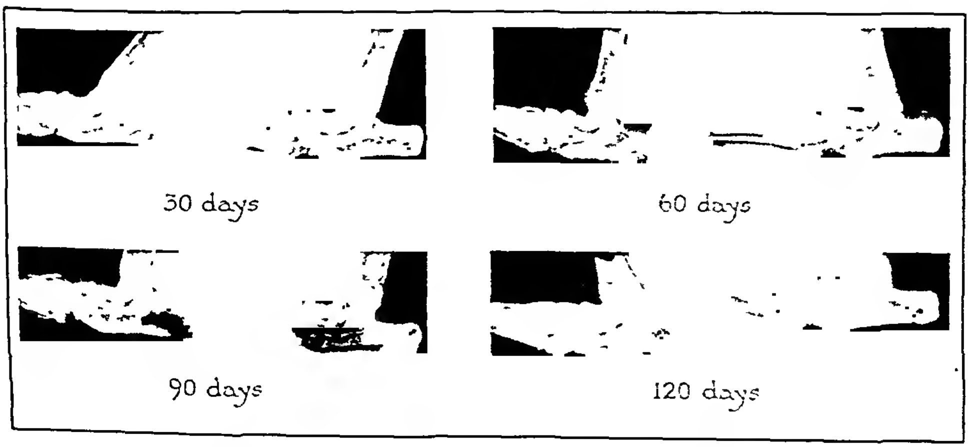

FIG. 3
Roentgenograms taken at various intervals after denervation.

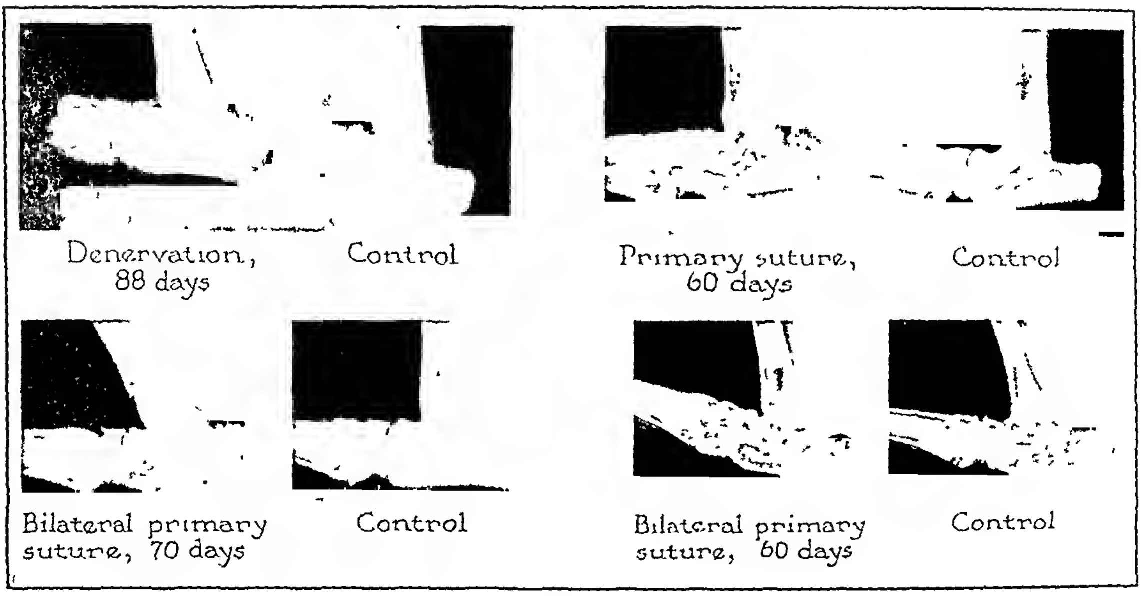

FIG. 4

Roentgenograms at upper left were taken eighty-eight days after denervation of left sciatic nerve; those at upper right were taken sixty days after primary suture of left sciatic nerve. Lower roentgenograms were taken seventy and sixty days, respectively, after bilateral primary suture and immobilization in a cast. Ulcers were present in all.

extremities: Four were x-rayed at 30 days, two at 60 days, three at 90 days, and three at 120 days after section (Figs. 1, 2, and 3.).

Of eleven animals in which an ulcer had developed at some time, some bone change was demonstrated in only one. This was an animal examined 132 days after denervation, and the ulcer of the heel was still present. In five of the other ten, the ulcer had healed; in three it remained unhealed; in one only a denudation remained; in one the ulcer appeared only six days before the animal was sacrificed, ninety days after primary suture.

Roentgenograms were available of eighteen extremities which, after primary suture or denervation, were immobilized in a bivalved plaster cast. Of the eighteen, ulcers developed in eleven. When primary sutures were performed upon both sciatic nerves, one hind extremity was immobilized in a bivalved plaster cast; the other side served as a control. No change in bone could be shown in the extremities in which ulcers had not developed. Of the eleven with ulcers, changes in the bone could be demonstrated in five. In three, the persisting ulcers were large and deep; in two, only scabs were discerned over the heels (Fig. 4).

The changes which were observed consisted of a definite, although slight, atrophy in the tarsal structures. The criteria for determining the existence of bone atrophy were (1) general demineralization and (2) preservation of density in the articular cortex. In one animal, there was local bone destruction of the posterior aspect of the calcaneus (Fig. 4).

Changes in bone were never demonstrable by roentgenogram when ulceration had not occurred at the heel or knee, whether or not the extremity had been immobilized after nerve injury.

The degree of ulceration in the group of immobilized animals was greater than in the other groups, some of which had had bilateral operations. Since those immobilized, but without ulcers, showed no demonstrable change in bone, the change in the animals with ulcer could not be attributed either to disuse or to loss of some "trophic influence" upon bone. It is possible that, when ulcers develop in immobilized extremities, circulatory disturbances may facilitate bone changes.

CONCLUSIONS

These experiments indicate that atrophy of bone does not result from denervation of an extremity, or from immobilization of a denervated extremity. When atrophy of bone

was observed, in rare instances, it occurred as the result of ulceration overlying the bone and joint. When ulceration occurred in extremities which had been immobilized and denervated, it was more severe than in cases in which the extremity had not been immobilized, and a greater number of cases of bone atrophy occurred.

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CONTRACTURES FOLLOWING EXPERIMENTALLY PRODUCED PERIPHERAL-NERVE LESIONS *

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The development of contractures in certain muscles following peripheral-nerve injuries has been recognized by such authors as Goldstein and Lehmann as a common and dreaded complication. The contractures develop as a result of a variety of causes.

They have frequently been described (by Goldstein, Lehmann, Léri and Roger, Guillain and Barré, and Foerster) in the antagonist of a paralyzed muscle, in which the contracture was due to an adaptive shortening of the actively innervated muscle, because of the lack of opposition by the paralyzed muscle. Foerster [9] called these *"Schrumpfungskontraktur"* and Ranson and Sams applied the term "myostatic contracture". Such a muscle cannot be extended passively without undue force and pain, nor does it yield under narcosis unless excessively severe force is applied. Eventually capsular changes occur, followed by bony fixation.

Other contractures develop in muscles, the nerves of which are irritated or compressed by a foreign body or by scar tissue [9, 13, 17]. Lehmann considered these to be active contractures, due to excessive stimulation of motor fibers.

Painful nerve lesions yield contractures, for example, in the irradiating neuritis of Guillain and Barré and the painful neuritis of Athanassio-Benisty. Lehmann, Guillain and Barré, and Foerster have described contractures in painful neuromata, in which the neuroma produced limitation of motion. In this group the contractures developed as a result of irritation of sensory fibers. Lehmann referred to them as *"neurogene Schonungskontrakturen"* (neurogenic protective contractures). Athanassio-Benisty pointed out the importance of reflex phenomena in the development of such contractures; she cited cases in which the wound did not involve any important nerve, and yielded contractures in muscles which were sometimes on the opposite side of the body.

Babinski and Froment described *"paralysie d'ordre réflexe"*, which is known in the English literature as the physiopathic reflex contracture, or congealed hand or foot. It was accompanied by trophic, vasomotor, and thermic changes. Froment has reviewed the more recent investigations, indicating that the phenomena were the result of involvement of sympathetic fibers and were not due to hysteria, as claimed by others. These contractures sometimes followed mild injuries to the extremity, not involving the nerve [19], hence adding support to the concept that, at least in part, they were produced reflexly.

Some contractures are due to fascial shrinkage [16],—for example, in cases in which Dupuytren's contracture followed a lesion of the ulnar nerve. This was supposedly due to involvement of trophic fibers, and it was noted that inflammation surrounding trophic ulcers contributed to this deformity.

Contractures may develop in denervated muscle. Lovett and many others have described the shortening of non-paralyzed muscles in cases of poliomyelitis. More recently, Steindler and his associates have recorded them in 25 per cent. of 200 cases of poliomyelitis, in some of which the contractures were in paralyzed muscles which had been immobilized for from three and one-half weeks to eight months. The limitation of joint movements in these cases is due to muscle shortening, and not to articular or peri-articular changes. Foerster [8] also mentioned that muscle, deprived of efferent nerve fibers, could

* The work described in this paper was done under a contract recommended by the Committee on Medical Research, between the Office of Scientific Research and Development and Northwestern University.

"adapt" itself to a certain degree by shortening when its origin and insertion were approximated, and that this was due in part to the elasticity of such muscle. Tower has shown that, following denervation, a set contracture gradually develops in muscle, which is insidious in onset and is delayed for six to eight weeks. It is not relaxed by general anaesthesia or ischaemia, or in death. However, after re-innervation, even high-grade contractures could be partially reversed. Tower also referred to the fact that contracture does not develop in denervated muscles which are subjected to gravity strain, presumably because the muscle is stretched instead of shortened.

Many investigators, including Goldstein, Lehmann, Athanassio-Benisty, and Foerster[8], have referred to the importance of psychic factors in the development of contractures, believing that immobilization initiated the deformity and that its maintenance was determined by conscious or unconscious influences. Claude stated that in many patients, left to themselves or poorly treated, the abnormal attitude, which was first acquired reflexly because of pain or for protection, becomes fixed, perhaps due to hysterical influences or habit. Similar views were held by others in a discussion of this subject at the Paris *Société de Neurologie* in 1916[3].

Finally, it must be borne in mind that, when a missile produces a nerve injury, it may also damage neighboring tissues. Athanassio-Benisty considered osseous musculotendinous lesions to be one of the important causes of contracture.

Despite the importance of the problems presented by contractures, surprisingly little experimental work has been done in this field. Some investigators have studied the influence of immobilization upon the development of contractures in the presence of the intact or selectively damaged nervous system.

Fröhlich and Meyer stated that immobilization of a denervated extremity of a cat for four or five days did not yield stiffness of the extremity, as would be the case if the nerve were intact. Meyer and Spiegel found that posterior-root section, followed by immobilization for four weeks, yielded no contracture, whereas immobilization of a normal extremity for four days did lead to such a contracture. They believed these contractures to be neuromyogenic, the reflex shortening being the preliminary condition and the myogenic shrinkage following. Spiegel and Shibuya referred to this as "*Ruheversteifung*" (immobilization stiffness).

Riemke claimed that the functional contracture appeared quickly and was followed in two or three days by secondary organic changes in the muscle, connective tissue, tendons, ligament, and joint capsule. The longest period of immobilization he studied was seven days.

Bier opposed the belief that *Ruheversteifung* was dependent upon the intact nervous system only, claiming that it was always seen in the presence of inflammation or injury to the tissues. Hueter, as quoted by Fick, claimed that the prolonged approximation of the ends of a muscle was always followed by "*nutritive Verkürzung*", and that it occurred in paralyzed as well as unparalyzed muscles. Fick studied the shortening of immobilized muscles by actually measuring the fibers. His experiments were of short duration. He agreed with Meyer and Spiegel that the integrity of the reflex arc was necessary for the development of contracture, although he admittedly had contradictory results. For example, in one rabbit he sectioned the brachial plexus, thus denervating the extremity. Then he fractured the foreleg and immobilized the extremity in partial flexion at the elbow. After ten days, he found some shortening of the muscle fibers, which must have developed independently of nerve influences.

Ranson and Sams studied the development of contracture in the gastrocnemius after division of the Achilles tendon. They believe that this "myostatic contracture" is dependent upon the nervous system in its genesis only, and that its persistence is independent of innervation, anaesthesia, or section of the motor nerve. In effect, their experiment showed that contracture will develop in an innervated muscle, if the muscle is unopposed.

The role played by the nervous system in the development of contracture is by no means clear. Most of the experimental work suggests that the nervous system is necessary but Tower has shown clearly that contracture will develop in six to eight weeks in a denervated muscle. Most of the other investigators failed to find it in immobilized denervated extremities, perhaps because they terminated their observations in from one to four weeks. Furthermore, there is confusion as to what constitutes a contracture, some considering it to be any degree of transient stiffness which opposes easy stretching.

There is no definite investigation in the literature which deals with contractures following peripheral-nerve injuries in circumstances which are analagous to those occurring in the human. In such instances, at least partial immobilization is used. Furthermore, at one time we are dealing with denervated muscles, and at another time with muscles that are being re-innervated. The following report deals with the development and treatment of contractures in the muscles of the cat's leg, following experimentally produced lesions of the sciatic nerve.

MATERIALS AND METHODS

Three types of lesions of the sciatic nerve of the cat's leg were available.

A. Denervation: The sciatic nerve was sectioned at about 4 centimeters below the sciatic notch, and the distal stump was resected for 2.5 to 3 centimeters. One cubic centimeter of absolute alcohol was injected into the central stump.

B. Primary Suture: The sciatic nerve was sectioned, 4 centimeters below the sciatic notch, the ends were immediately approximated, and the epineurium was sutured.

C. Delayed Suture: The sciatic nerve was divided, 4 centimeters below the sciatic notch. The ends were turned back to avoid their reunion. When the suture was made, sixty days later, the retracted and neuromatous nerve ends were first resected for from 3 to 5 centimeters.

In all the sciatic-nerve preparations, the muscles below the knee were paralyzed, so that the foot was flail. In walking, the foot and toes could not be elevated high enough to clear the floor, so that the cat stepped on the dorsum of the toes. In standing, the heel rested on the floor.

In some peroneal-nerve preparations, primary sutures were studied; the level of the section was the same as in the sciatic preparations, except that care was taken not to cut the tibial part of the nerve. This produced drop foot and toes, without paralysis of the plantar flexors of the foot and toes. Such a cat could stand with its heel off the floor.

No form of immobilization was used. The animals were confined to individual cages, eighteen by twenty-four by sixteen inches, where they were usually in a sitting or lying position, with acute flexion at the ankle and knee. They were removed either for daily treatment or for examinations at intervals of five to ten days, when they were permitted to walk around.

METHOD OF EXAMINATION

Only contractures of the following muscles were considered, because they were large palpable muscles: (1) gastrocnemius, (2) tibialis anterior, (3) extensor digitorum longus, and (4) flexor digitorum longus.

One must choose arbitrary but definite positions of the joints involved in examining the extremities, because variations in the degree of flexion or extension in these joints will make the muscles appear to be longer or shorter.

To test the gastrocnemius, the knee is maintained at a right angle. Normally the foot will dorsiflex so as to touch the anterior surface of the leg, executing an arc of 90 degrees. If the arc executed is only 60 degrees, then the measure of contracture of the gastrocnemius is 30 degrees. To test the tibialis anterior, the thigh and leg are maintained in a straight line. With the limb in this position, the ankle extends normally to 180 degrees. Any limita-

tion in extension of the ankle is due to a contracture of the tibialis anterior, the taut tendon of which can be palpated. In testing for the extensor digitorum longus. the knee is maintained at right angles; normally the ankle can then be extended to 180 degrees. Any limitation of this—for example, to 150 degrees—would mean a contracture of the extensor digitorum longus of 30 degrees. To test for the flexor digitorum longus, the knee and ankle are held at a right angle. With the limb in this attitude, the toes normally may be flexed completely, so that the claws touch the plantar surface of the foot, executing an arc of 180 degrees. From the horizontal plane, the toes may extend through an arc of only 90 degrees. Any limitation of this would be a measure of the contracture of the flexor digitorum longus.

With a little experience, one could detect whether the limitation in the range of motion was due to voluntary resistance or to actual muscle shortening. The tendon of the shortened muscle could be palpated and compared with that on the normal side. When a muscle displayed contracture, the animal was examined under anaesthesia prior to sacrifice, to confirm the finding. Then, when the animal was sacrificed, the taut tendons were cut to see if the limitation of joint motion was due to contracture or to arthritic and capsular changes. In all of the animals, it was found that the limitation was due to muscle shortening.

All angles of motion were estimated visually. It is difficult to be sure by this means of estimation that a limitation of motion of only 10 degrees is pathological, so that contractures of less than 15 degrees were eliminated as non-significant.

TYPES OF TREATMENT

A. No Treatment.

B. Massage and Passive Motion: The massage consisted of thirty-six to fifty strokings and twenty-five to thirty-five kneading movements for the entire extremity for a total duration of five minutes daily. Passive motion followed massage. The knee and ankle were moved simultaneously, by alternating flexion of the knee and dorsiflexion of the foot with extension of the knee and plantar flexion of the foot. Alternate flexion and extension of all the toes were performed simultaneously. Each joint was passively moved ten times, care being taken to carry the movement through its full range.

C. Massage, Passive Motion, and Electricity for Five Minutes: To Group B, electrotherapy was added for five minutes daily. Bipolar stimulation to the gastrocnemius was used; the stimulating interrupter key electrode was applied as closely as possible to the origin of the muscle, and the other was an indifferent electrode, close to the insertion of the Achilles tendon. The area of each electrode head was about two square centimeters, and was protected by chamois. Stimulation was given the gastrocnemius by the periodic application of a sixty-cycle alternating current; the current was allowed to flow for three-second intervals and was interrupted for two-second intervals, so as to get twelve contractions per minute. The current strength was adapted in each treatment, so as to produce a prolonged submaximal tetanic contraction with as weak a current strength as possible.

D. Massage, Passive Motion, and Electricity for Fifteen Minutes: This varied from Group C in that electrotherapy was given for a longer interval daily. The sixty-cycle alternating current was interrupted every one and one-half seconds by means of a motor-driven mechanical device, so that forty submaximal tetanic contractions of the muscle were produced each minute for fifteen minutes.

DATA AND DISCUSSION

Before a muscle was accepted as displaying contracture, shortening of the muscle was demonstrable by limitation in the motion of the involved joint and actual palpation of the tendon on stretch. In those animals which displayed contracture at the time of sacrifice, the further criteria were that the contracture must persist under deep narcosis and in death. Furthermore, when the tendons about the joint were severed, complete range of motion in the joint must be possible.

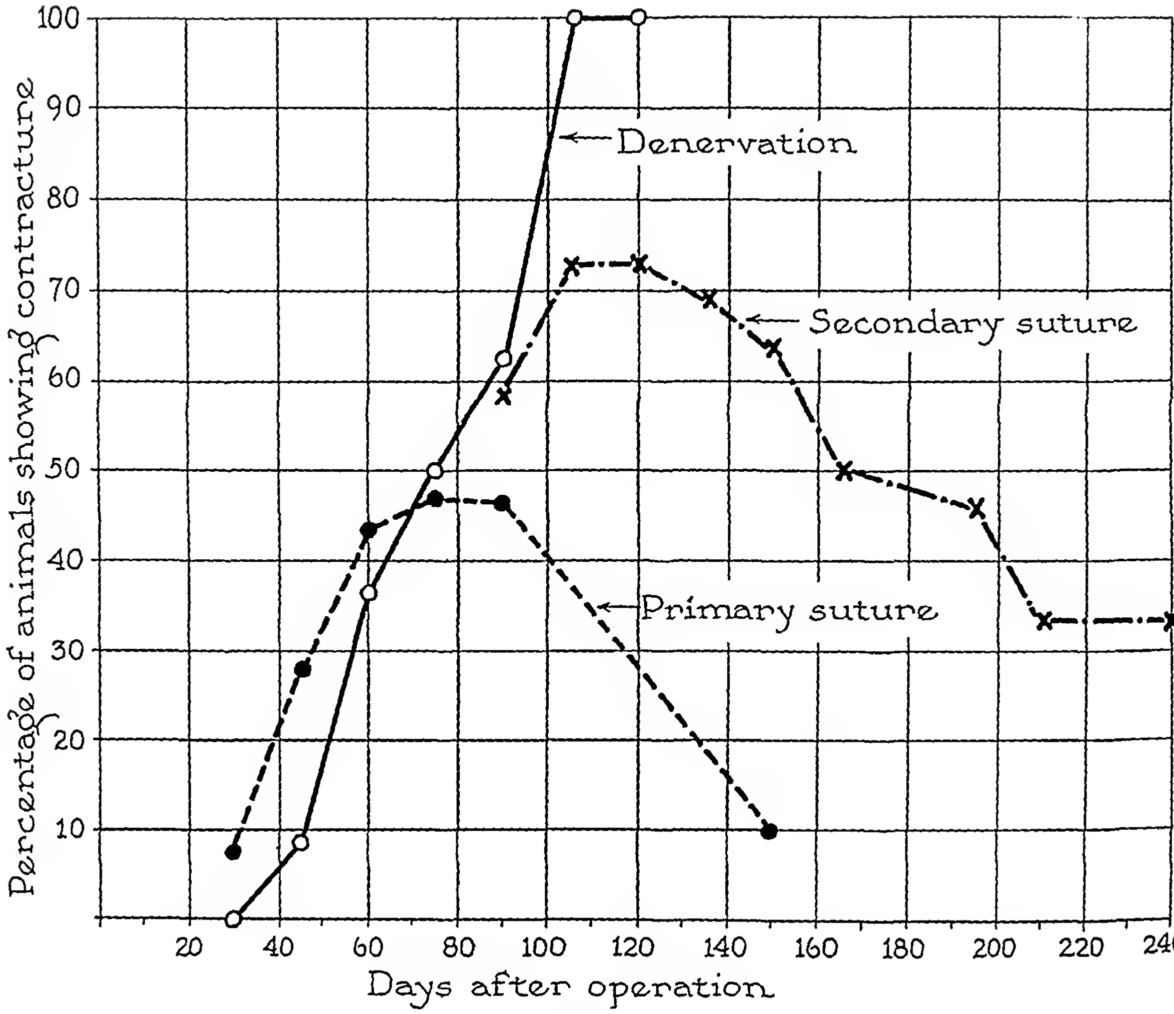

FIG. 1

Frequency of contractures in untreated dorsiflexors of the foot after secondary suture of the sciatic nerve, as compared with frequency after denervation and after primary suture.

A. Denervation Contractures in Untreated Animals

In this series of fifteen animals, of which five survived to 120 days, contractures began to appear in thirty to forty-five days. By 105 days they were present in 100 per cent. of the cases (Fig. 1). They were seen only in the dorsiflexors of the foot. In other experiments where immobilization was used, shortening was evident also in other muscles. It appears that contractures will develop in muscles which are relatively fixed in a shortened state.

The only treatment given these animals was massage and passive motion for fifteen minutes, and it had no beneficial effect. It appeared probable that, if all the animals had been allowed to survive for 120 days, the severity of the contractures in all would have increased to 80 or 85 degrees. These contractures were firm and practically inextensible. They did not yield under nembutal or ether narcosis, or in death. A spot survey of the pathological findings in some of these muscles showed an excessive amount of fibrous tissue, as compared with the normal. The reason for the fixed shortening in the absence of nerve influences is a problem which awaits further study.

B. Contractures after Primary Suture in Untreated Animals

Contractures appear in a large number of the muscles of cats after the nerve has been sectioned and sutured immediately. Of nineteen animals, treated and untreated, contracture was present in sixteen (84.2 per cent.) ninety days after primary suture of the sciatic nerve. The contracture occurred in one or more of the muscles, producing dorsiflexion and plantar flexion of the foot or toes. Eleven animals had contracture of the dorsiflexors of the

foot, seven of the dorsiflexors of the toes, seven of the plantar flexors of the foot, and eight of the plantar flexors of the toes. This high frequency shows the gravity of such a complication after peripheral-nerve injury.

It is evident that contractures develop most frequently in the dorsiflexors of the foot,—that is, either in the tibialis anterior, the extensor digitorum longus, or both. Because of the greater frequency in this muscle group, it was chosen for more extensive study and analysis of contractures in general.

Contractures in Dorsiflexors of the Foot after Primary Suture in Untreated Animals

In Table I are data showing the development of the frequency and severity of this group of contractures. The peak frequency is reached at seventy-five days (Fig. 1). Until this time, the line of ascent is a little more rapid than that for the denervated dorsiflexors of the foot. However, beyond this time, there is a sharp divergence between the two, in that contractures increase after denervation up to 100 per cent. at 105 days; whereas in the cases of primary suture, the peak of frequency is passed after 75 days, and there is a decline to 10 per cent. at 150 days.

In the group with primary suture the peak severity, reached at seventy-five days, does not recede until after ninety days, whereas in the denervation group there is no recession.

For a certain period of time after section and immediate suture of the sciatic nerve, all the muscles below the knee are in a state of denervation. For the dorsiflexors of the foot, the average time of return of function in these animals was sixty-two days, with a minimum of forty-nine days and a maximum of eighty-three days. It is considered by Gutmann, Guttmann, Medawar, and Young that re-innervation takes place some days before function returns. Thus, in animals having primary suture, contractures may develop as a result of the influence of denervation and shortening (which appear as early as thirty to forty-five days); and, secondarily, due to the influence of re-innervation, even before function occurs. This is considered to be true because there are significantly more contractures in animals having primary suture than in denervated animals at forty-five and sixty days after suture (Fig. 1). This is a time when function has not frequently been manifested. However, by seventy-five days it is noted that the denervation contractures surpass the primary-suture contractures in frequency and severity, and it is believed that this is due to the return of function in the group with primary suture. It must be recalled that no immobilization was used in these animals, so that where the function did return, the animals used their extremities more freely to exercise them spontaneously.

At first the contractures were rather elastic and the muscles could be stretched without much pain, so as to produce the complete range of motion at the ankle joint. As the contractures persisted, they became fixed, so that attempts at stretching the muscle were exceedingly painful; and in many instances little, if any, improvement could be obtained in the range of movement of the involved joint. Under nembutal or ether anaesthesia, these contractures were no more reducible with moderate force than they had been without narcosis.

Various correlation studies were made to determine what factors could be considered to contribute toward the development of contracture. There was no relation between the presence of contracture in the dorsiflexors of the foot and the percentage of weight loss in these muscles; nor was there any relation between the percentage of weight loss of the gastrocnemius and the contracture in the dorsiflexors, even though one might anticipate a more marked weight loss in the group with contracture, because then the gastrocnemius might be said to be on stretch.

The presence of fibrillation, ninety days after primary suture, was sought by direct observation of the muscle, with the animal under anaesthesia. Of ten animals showing contractures at this time, one (10 per cent.) showed fibrillation. Of twenty-nine without

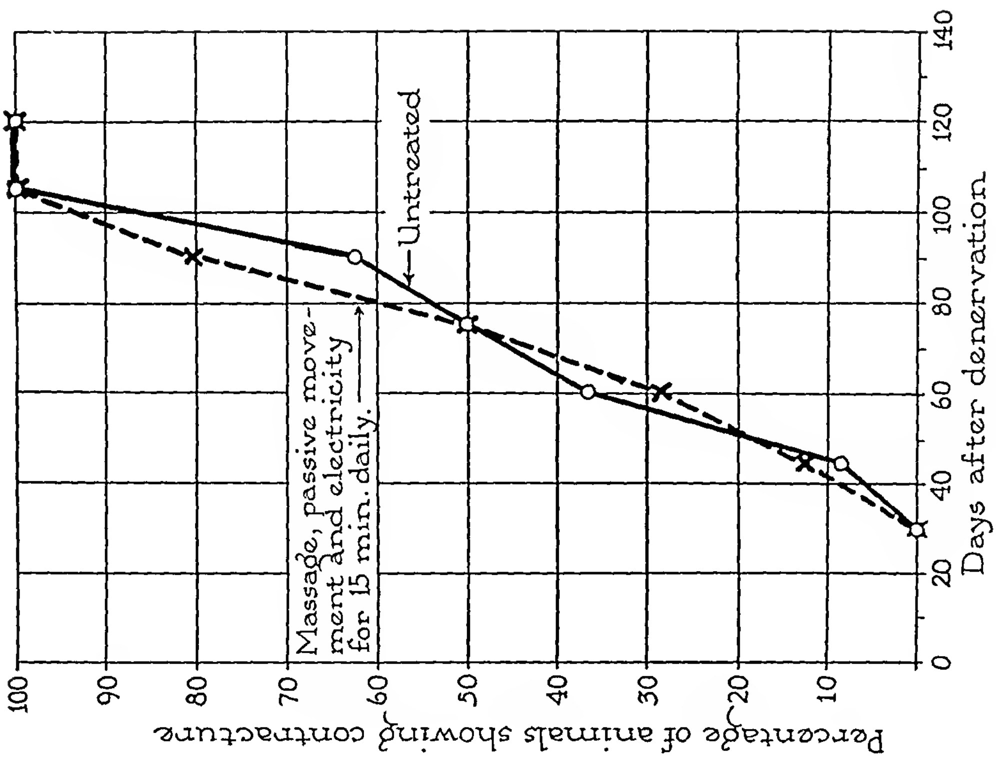

Fig. 3

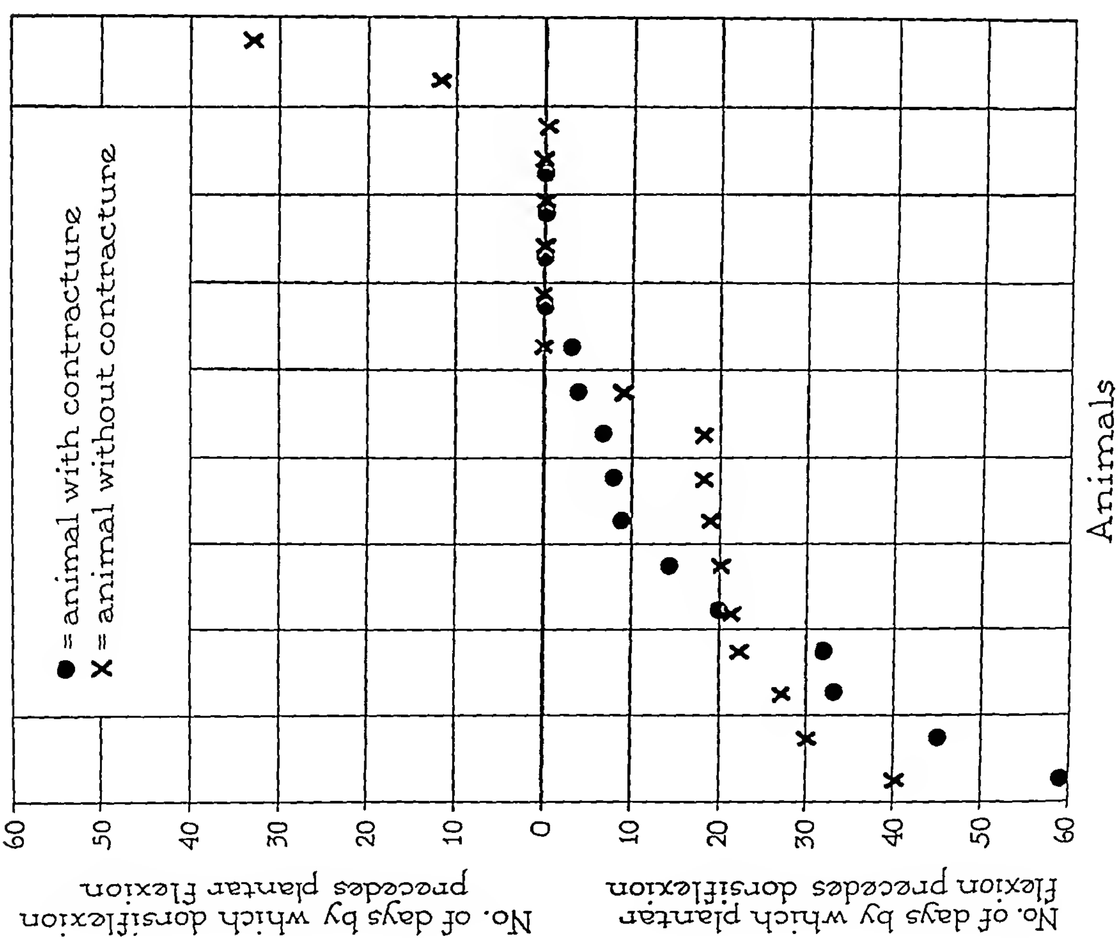

Fig. 2

Fig. 2: Development of contracture in plantar flexors of toes in animals having primary suture, as related to difference in number of days between recovery of function of plantar flexors and that of dorsiflexors of the toes.

Fig. 3: Development of contractures in denervated dorsiflexors of the foot, with and without treatment.

contractures, seven (24.1 per cent.) showed fibrillation. There was a significantly lower frequency of fibrillation in those muscles with contracture.

No significant difference was seen in the specific gravity of muscles with or without contracture.

Of sixteen animals with ulceration of the heel, four showed contracture of the dorsiflexors of the foot. These data are not sufficient to determine the importance of ulceration in contractures, because most of the animals with serious ulcer were discarded.

In a selected group of twenty-nine animals which survived ninety days after primary suture, it was found that the development of contracture was not related to the time of recovery of function in the paralyzed muscles. The average time for recovery of function in the contracture group was sixty-one days, as compared with sixty-three days for those without contracture.

After sciatic-nerve section, opposing muscles regained function at different times. The longer the difference in time between the recovery of opposing muscles, the more likely was the development of a contracture in the muscle which recovered first (Fig. 2). Of fifteen animals with contracture of the plantar flexors of the toes, there was none in which function returned to the dorsiflexors first. In four, function returned simultaneously to the dorsiflexors and plantar flexors; and in the remaining eleven (73.3 per cent.), recovery of the plantar flexors preceded that of the dorsiflexors. In eighteen animals without contracture in the plantar flexors of the toes, there were only ten (55.5 per cent.) in which recovery of the plantar flexors preceded that of the dorsiflexors; and in most instances it was to a less significant extent than in the animals with contracture. In six, recovery of function in both groups was simultaneous; and in two animals, recovery of function in the dorsiflexors preceded recovery in the plantar flexors of the toes. However, the return of function in the opposing muscles in a non-immobilized animal will tend to dissipate a contracture quickly.

In a few animals, in which either the dorsiflexors or the plantar flexors of the foot had been denervated alone, contracture developed in the muscle group which retained its innervation. This is due to the principle just described, in which opposing muscles recover function at different times.

C. Contractures after Delayed Suture in Untreated Animals

In a selected group of fifteen cats, sciatic-nerve suture was delayed for sixty days. At ninety days after suture, 100 per cent. showed contracture in one or more of the muscles producing dorsiflexion or plantar flexion of the foot and toes; this is even greater than the figure of 84.2 per cent. for animals ninety days after primary suture. Thirteen had contracture of the dorsiflexors of the foot, thirteen of the dorsiflexors of the toes, eleven of the plantar flexors of the toes, and only three of the plantar flexors of the foot. For purposes of analysis of a larger amount of material and for comparison with the studies on animals with primary suture, the development of contractures in untreated animals was confined to the dorsiflexors of the foot,—that is, a contracture in either the tibialis anterior or the extensor digitorum longus, or both.

The frequency of contractures of the dorsiflexors of the foot is certainly greater after delayed suture (72.7 per cent.) than after primary suture (47.1 per cent.). It is considered that the longer period of denervation favors this outcome (Table II).

The plotting of the days after operation for the animals with delayed suture (Fig. 1) was taken as the number of days after section of the sciatic nerve, which was sixty days before the nerve was resutured. This was done because actually, during this sixty days, the muscles were in a state of denervation; and any factor operating in the development of contracture in these muscles is equally as important as in those muscles which were denervated and not allowed to regain their innervation. Thus it will be seen that the first point for secondary suture is plotted at ninety days, which is actually only thirty days after

TABLE I

Analysis of Contractures of Dorsiflexors of the Foot at Varying Times after Primary Suture of the Sciatic Nerve with Different Types of Treatment

Days after Suture	No Treatment			MPM			MPME—5 min.			MPME—15 min.		
	No. of Animals	Contractures (Per cent.)	Contractures (Degrees)	No. of Animals	Contractures (Per cent.)	Contractures (Degrees)	No. of Animals	Contractures (Per cent.)	Contractures (Degrees)	No. of Animals	Contractures (Per cent.)	Contractures (Degrees)
30	26	7 7	20, 45	25	0	0	15	0	0	20	0	0
45	25	28.0	20, 20, 25, 30, 25, 35, 40	24	8 3	15, 30	15	0	0	17	0	0
60	23	43.5	15, 20, 20, 20, 30, 35, 40, 45, 45, 45	23	21 7	20, 20, 30, 30, 50	14	14.3	15, 20	13	38.4	20, 20, 35, 40, 40
75	17	47.1	15, 20, 30, 35, 35, 35, 40, 40	15	20 0	15, 20, 20	10	30 0	20, 40, 50	12	41.6	15, 20, 30, 35, 40
90	15	46 6	15, 20, 30, 35, 40, 40, 60	13	15 4	20, 20	10	40.0	15, 20, 40, 45	11	45.4	20, 25, 40, 45, 45

MPM = Massage and passive motion.
MPME—5 min. = Massage, passive motion, and electricity for five minutes.
MPME—15 min. = Massage, passive motion, and electricity for fifteen minutes.

TABLE II

ANALYSIS OF CONTRACTURES OF THE DORSIFLEXORS OF THE FOOT AT VARYING TIMES AFTER DELAYED SUTURE OF THE SCIATIC NERVE WITH DIFFERENT TYPES OF TREATMENT

Days after Suture	No Treatment			MPM			MPME—5 min.		
	No. of Animals	Contractures (*Per cent.*)	Contractures (*Degrees*)	No. of Animals	Contractures (*Per cent.*)	Contractures (*Degrees*)	No. of Animals	Contractures (*Per cent.*)	Contractures (*Degrees*)
30	12	58.3	15, 20, 25, 45, 60, 70, 70	10	20.0	15, 50	7	28.5	30, 50
45	11	72.7	15, 20, 30, 45, 45, 70, 70	9	33.3	20, 30, 50	7	28.5	30, 50
60	11	72.7	20, 20, 20, 30, 35, 40, 60, 80	10	60.0	15, 40, 40, 55, 60, 60	6	50.0	20, 30, 45
75	13	69.2	20, 20, 20, 30, 40, 45, 60, 70, 70	10	50.0	25, 35, 45, 45, 60	6	50.0	20, 20, 45
90	11	63.6	20, 20, 30, 45, 60, 60, 70	10	70.0	40, 45, 50	7	71.4	20, 20, 20, 45, 45
105	12	50.0	30, 30, 30, 35, 45, 55	11	54.5	20, 20, 20, 30, 40, 45	7	71.4	20, 20, 20, 40, 45
135	13	46.1	20, 20, 30, 30, 40, 65	11	45.4	20, 25, 35, 40, 45	7	71.4	20, 20, 20, 45, 60
150	6	33.3	30, 35	4	25.0	40	3	33.3	70

MPM = Massage and passive motion.
MPME—5 min. = Massage, passive motion, and electricity for five minutes.

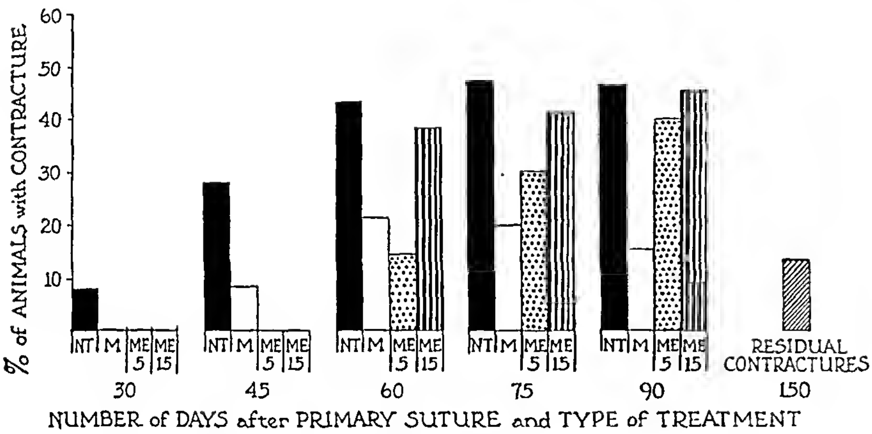

FIG. 4

FIG. 4

Frequency of contractures in the dorsiflexors of the foot at various intervals after primary suture of the sciatic nerve, various types of treatment being used.

NT = No treatment.
M = Massage and passive motion.
ME_5 = Massage, passive motion, and electrotherapy for five minutes.
ME_{15} = Massage, passive motion, and electrotherapy for fifteen minutes.

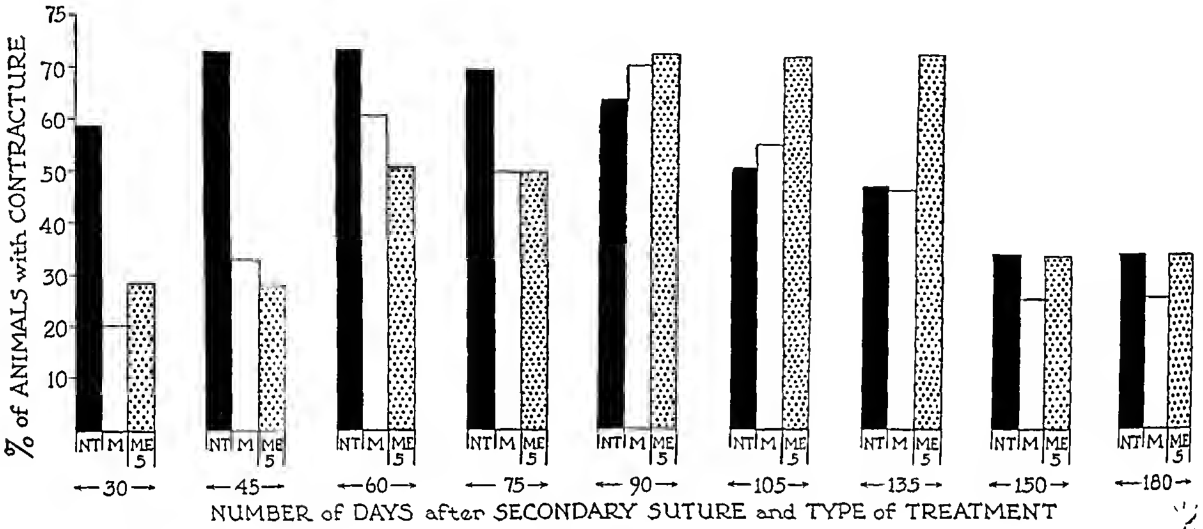

FIG. 5

Frequency of contractures in the dorsiflexors of the foot at various intervals after delayed suture of the sciatic nerve, various types of treatment being used.

suture. Since at this time it was impossible for the axon to regrow into the muscle, we are still dealing with a denervated muscle; and it may be seen that the curves for the delayed and denervated groups approximate each other. The recession from the peak frequency in the animals with both primary and secondary suture takes place spontaneously, as recovery of function occurs. There are more frequent residual contractures after secondary suture (33.3 per cent.) than after primary suture (10 per cent.) at 150 days after suture. A similar sequence of events is evident in reference to the severity of contractures. These facts are just cause for urging early operation after severance of a peripheral nerve.

D. Effect of Treatment upon the Development of Contractures of the Dorsiflexors of the Foot

The need of physiotherapy early after the occurrence of peripheral-nerve lesions has been amply recognized. Much has been said about the necessity of immobilizing the paralyzed muscle in a shortened position to prevent overstretching of the muscle fibers. Highet recently pointed out the value of therapy twice daily, and claimed that all involved joints should be exercised passively through their complete range of motion. He believed that transient stretching of a denervated muscle was beneficial in preventing contractures.

In a series of eleven denervated animals treated with massage, passive motion, and electrotherapy for fifteen minutes, there was no perceptible difference in the rate of development of contractures in the dorsiflexors of the foot as compared with the untreated group (Fig. 3).

In the animals having primary suture, there was no doubt but that massage and passive motion had definite value in decreasing the frequency and severity of contractures, as compared with the untreated group (Table I and Fig. 4). The peak frequency of 21.7 per cent. was reached at sixty days in the treated group, as compared with 47.1 per cent. at seventy-five days in the untreated group. The recession of contractures was better with this treatment.

In the group with delayed suture, massage and passive motion did not have such an obviously beneficial effect (Table II and Fig. 5). Although contractures occurred almost as frequently with this treatment (70.0 per cent.) as without it (72.7 per cent.), retardation of the peak frequency for forty-five days is valuable, because it brings the muscle into the period of recovery of function at which time the contracture can be dissipated more easily. The beneficial effect of massage and passive motion on the severity of delayed-suture contractures was more apparent than after primary suture.

The recession of contractures following primary suture could not be analyzed, because most of the animals were sacrificed at ninety days. After delayed suture, the contractures in untreated and treated animals recede at about the same rate. The explanation for this becomes apparent when we recall that, after recovery of function, these animals, which were not immobilized, were actually treating themselves by walking. The short period of massage and passive motion would thus be insignificant in comparison with this spontaneous form of active exercise.

The validity of the addition of electrotherapy to massage and passive motion has frequently been the cause of debate in the treatment of peripheral-nerve lesions. The discussion has usually concerned itself with its value in preventing atrophy or in producing an earlier or better return of function. The only two references which were found to deal with electrotherapy and contractures were simply statements of clinical experience. Elmslie, in a symposium on the treatment of peripheral-nerve injuries, mentioned that he saw many contractures and deformities, even with electrotherapy. Goldstein cautioned that electrotherapy may do more harm than good, and that there is a time when it can favor the development of contractures. Although he did not elaborate, he claimed that in a muscle with a tendency toward the development of contracture, electrical treatment will increase the contracture to a marked degree.

In the animals with primary suture, it was at least suggestive that, in the early postoperative period, electrical treatment has some influence in retarding the development and decreasing the severity of contractures (Fig. 4). The contractures did not appear until sixty days after suture, whereas in the groups without treatment and with massage and passive motion, they appeared earlier. From sixty days on, electrical therapy appeared to have a deleterious effect upon the influence of massage and passive motion, since the more intense the electrotherapy, the more closely did the frequency and severity of contractures approximate those in untreated animals. The fact that the peak with electrotherapy was reached later than in either of the other groups further suggests its deleterious influence, because the longer it was used, the more frequent and severe were the contractures. It will be recalled that electrical stimulation was given to the gastrocnemius and, in treatment, a brisk plantar flexion of the foot was obtained. Due to spread of the current, many of the animals showed a preliminary dorsiflexion of the foot, followed by the more pronounced plantar flexion. Thus it is probable that the dorsiflexors of the foot also received electrical treatment.

In a group of twelve animals, bilateral primary suture of the peroneal nerves was done at the same level as the total sciatic-nerve sections and sutures. The animals were permitted free mobility in their cages, and were allowed to survive eighty days. The left leg was treated only with electricity, as previously outlined, and the right leg was untreated. This type of therapy definitely contributed to the development of contractures in the unparalyzed antogonists of paralyzed muscles: In all but one (91.7 per cent.), tightness or

contracture of the gastrocnemius developed. Definite fixed contracture developed in seven (58.3 per cent.), and most of the contractures appeared late. In the untreated extremities a "tightness" or contracture appeared in the unparalyzed antagonist in only 33.3 per cent. of the cases, and was of transient duration. It is difficult to understand why electrotherapy should do this, but the answer may be found in histological studies.

The severity of contractures after primary suture was also aggravated by electrotherapy. Those animals treated with massage, passive motion, and electricity for five minutes showed more contracture than those treated with massage and passive motion alone. The amount of contracture, according to percentage of animals, for those treated by massage, passive motion, and fifteen minutes of electrotherapy, was practically identical with that for the untreated group at ninety days.

In the delayed-suture group, insufficient animals were treated with massage, passive motion, and electricity for fifteen minutes, so they were omitted. In those treated for five minutes, the influence of electrotherapy was somewhat similar to that in the animals with primary suture (Fig. 5). The development of contractures in this group kept pace with the group treated only with massage and passive motion. Electricity, even for five minutes, seemed to retard the recession of contractures beyond ninety days after suture, because the peak of 71.4 per cent. was maintained until 135 days; at that time, untreated animals had a frequency of 46.1 per cent., and animals treated with massage and passive motion had a frequency of 45.4 per cent. Beyond 135 days, all three groups had approximately the same frequency (25 to 33.3 per cent.).

Influence of Treatment upon the Reversibility of Contractures

It was found that treated muscles were more pliable, even when showing contracture. With moderate or mild force, they could be stretched so as to produce the full range of motion, with the production of relatively little pain.

In a series of twenty-two primary animals with contractures of the dorsiflexors of the foot, the contracture had entirely disappeared in five (22.7 per cent.) by the time they were sacrificed. Of these five, there were three untreated and two treated animals. Similarly, in a series of twenty-seven animals with delayed suture, which showed contracture of the dorsiflexors of the foot at some time during life, nine had lost their contracture by the time they were sacrificed. Of these, four were untreated and five were treated. Contractures can reverse themselves, regardless of treatment.

Influence of Immobilization on the Development of Contractures

An attempt was made to obtain a series of cats which had had various forms of treatment, plus immobilization. The immobilization was produced by a plaster cast, which encased the animal from the mid-thorax downward. Some of the experiments were unilateral: One lower extremity only was encased in a position with both the knee and the ankle at right angles, whereas the other lower extremity was permitted to be free. Other experiments were bilateral, so that both lower extremities and the body were encased in plaster. This cast was so constructed that the posterior portion of it could be removed daily for treatment or examination of one or both legs. The posterior portion of the cast could then be replaced and strapped into place, so that effective immobilization continued. In spite of numerous attempts with various types of casts, ulceration invariably developed, either at the knee or ankle or at both sites, after about two or three weeks. Some of these animals could be nursed along, so that they survived for a period of time, as will be indicated later, without being in too bad a condition.

Although the number of animals in this series was not great, the results shed some light upon the development of contractures. In those animals which were immobilized without having had nerve section, no contractures developed after immobilization for as long as ninety days. This is difficult to reconcile with the statements of various authors

hat contractures, persisting under narcosis and in death, could be produced after immobilization for perhaps one or two weeks. However, it is more in agreement with the clinical xperience in those cases without bone or joint disease.

Denervation, followed by immobilization for ninety days, permits the development of contractures in all muscle groups. Contracture did not develop in one untreated animal with primary suture, which survived thirty-two days; but did develop in two others which survived sixty and ninety days, respectively.

Similarly, in the primary animals with bilateral immobilization, contractures began to appear at twenty-eight days; and by sixty days they became universal in the dorsal and plantar flexors of the foot, regardless of electrotherapy. It appears to take about thirty days for contractures to develop after primary suture and immobilization, but within the next thirty days they develop frequently and rapidly. Because of the scanty material, one cannot say how much of this is due to denervation and how much to re-innervation. However, it is obvious that immobilization greatly increases the frequency of development of contractures.

CONCLUSIONS

1. Contractures do not develop in the normal extremity of a cat, immobilized for as long as ninety days; but do develop in denervated muscles, if they are maintained in a shortened position for from forty-five to 105 days.

2. After primary suture of the sciatic nerve in cats, contractures occur in 84.2 per cent. of cases in one or more muscles below the knee, and after delayed suture in 100 per cent. of cases, after ninety days.

3. Contractures occur most frequently in the dorsiflexors of the foot of the cat after section and suture of the sciatic nerve. They are less severe, less frequent, and less persistent after primary suture than after delayed suture in untreated animals. Residual contractures are more frequent after delayed than after primary suture.

4. Massage and passive motion definitely decrease the frequency and severity of contractures of the dorsiflexors of the foot, which occur after primary suture. After delayed suture, this type of treatment seems only to retard the development of the peak frequency of contractures for forty-five days, but it undoubtedly decreases their severity.

5. The addition of electrotherapy to massage and passive motion delays the appearance of contractures for a longer period after primary suture than does the latter alone. Thus electrotherapy may have some beneficial influence in the early postoperative period. The longer the period of electrotherapy, the more closely do the frequency and severity of contractures approximate those in untreated animals. Electrotherapy favors the development of contractures in the unparalyzed antagonists of paralyzed muscles. It seems to retard the dissolution of contractures which occur after delayed suture.

6. Spontaneous movement of the animal after recovery of function can serve to dissipate a contracture, no matter what influences tend to preserve it.

7. Contractures are more frequent after section and suture of the sciatic nerve of cats, if the extremity is immobilized, than if the extremity is permitted to be free.

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DISLOCATION OF THE PISIFORM

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Dislocation of the pisiform bone is a rare entity. It is still more rare to have chronic recurrent dislocation of the pisiform. The case to be reported is believed to be the first complete description of such an entity. It warrants mention in view of the resulting disability, and because of the difficulty in diagnosis.

By 1901, Fergusson, Erichsen, Gras, Buchanan, Barois, Oberst, and Eigenbrodt had reported cases of dislocation of the pisiform. Practically all of the cases antedated the discovery of roentgen rays. Cohen states that Van der Donck, in 1899, reported a case of dislocation due to a fall, in which the roentgenogram "showed the pisiform between the radius, semilunar and cuneiform". The bone was removed, and marked improvement of the disability resulted. Cotton, in 1910, reported a case in which a painful mobile pisiform followed a fall; the bone clicked with motion. There was also some sensory disturbance of the ulnar nerve. No mention was made of a roentgenogram or of reduction, and the case was lost sight of after several weeks of immobilization.

Ozenne, in 1911, reported two cases. In the first case, the injury occurred secondary to lifting. No roentgenograms were taken. Clinically, the pisiform was palpated at the styloid process of the ulna, creating a depression at the normal site of the pisiform. The dislocation was not corrected by two weeks of immobilization. After six months, there was some limitation of adduction. In the second case, seen ten years after the injury, the dislocation had also resulted from lifting.

Cohen, in 1922, reported the case of a boy who dislocated his pisiform by a fall upon his hand. In addition, he received a backward displacement of the radial epiphysis. The pisiform was palpated at a higher level and was abnormally mobile. A gauze pad, pulling distally, was strapped over the pisiform, and the wrist was placed in flexion. Reduction of the pisiform was not determined, since the roentgenogram was not satisfactory for interpretation. After fifteen days, function was returning rapidly; but thereafter the patient failed to report.

Mather, in 1924, reported a case in which, after the patient had lifted a weight, something "gave" in the wrist. Mather stated that the roentgenograms showed the pisiform to be between the triangular bone and the ulna. The wrist was splinted in full flexion for three weeks. No mention was made of roentgenograms after reduction, or of manipulation to reduce the dislocation before application of the splint. Since the patient continued to have pain, the pisiform was removed. Complete return of function occurred in five weeks.

Wagoner, in 1930, reported a dislocation of the pisiform secondary to a fall on the hand. There were also fractures of the same area, involving the head of the radius and the styloid process of the ulna. Wagoner stated that roentgenograms showed the pisiform to have rotated through its upper pole, downward and inward. The dislocation was reduced under general anaesthesia and by means of fluoroscopy, and the wrist was placed in a cock-up splint. The result was excellent in five weeks.

The pisiform bone lies in the proximal row of carpal bones and articulates dorsally with the triangular bone. The volar surface is roughened, offering attachment to the transverse carpal ligament, *abductor digiti quinti*, and *flexor carpi ulnaris*. The latter prolongates to form the pisohamate and pisometacarpal ligaments. The volar branch of the ulnar nerve and the ulnar artery pass lateral to the pisiform.

Dislocation of the pisiform may result either from a direct injury or from muscular violence. In the cases reported, the ratio was two to one in favor of muscular force as an etiological agent. This force in all instances was manifested as the patient was in the

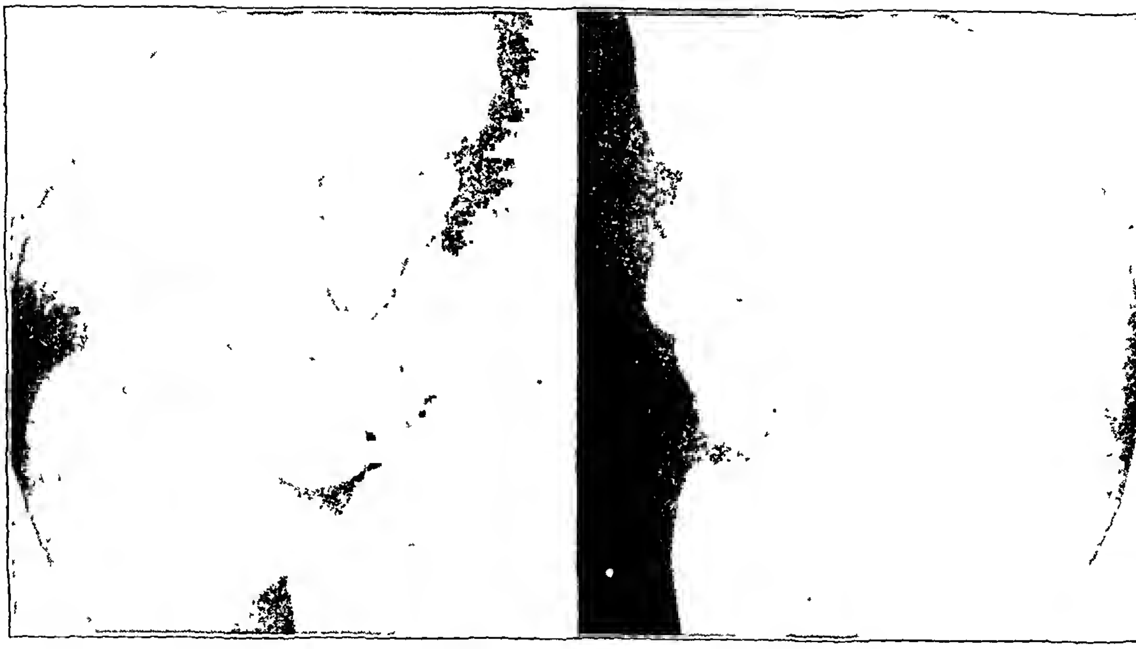

Fig. 1-A Fig. 1-B

Fig. 1-A: Anteroposterior view of normal right wrist.
Fig. 1-B: Anteroposterior view of left wrist, demonstrating dislocated pisiform.

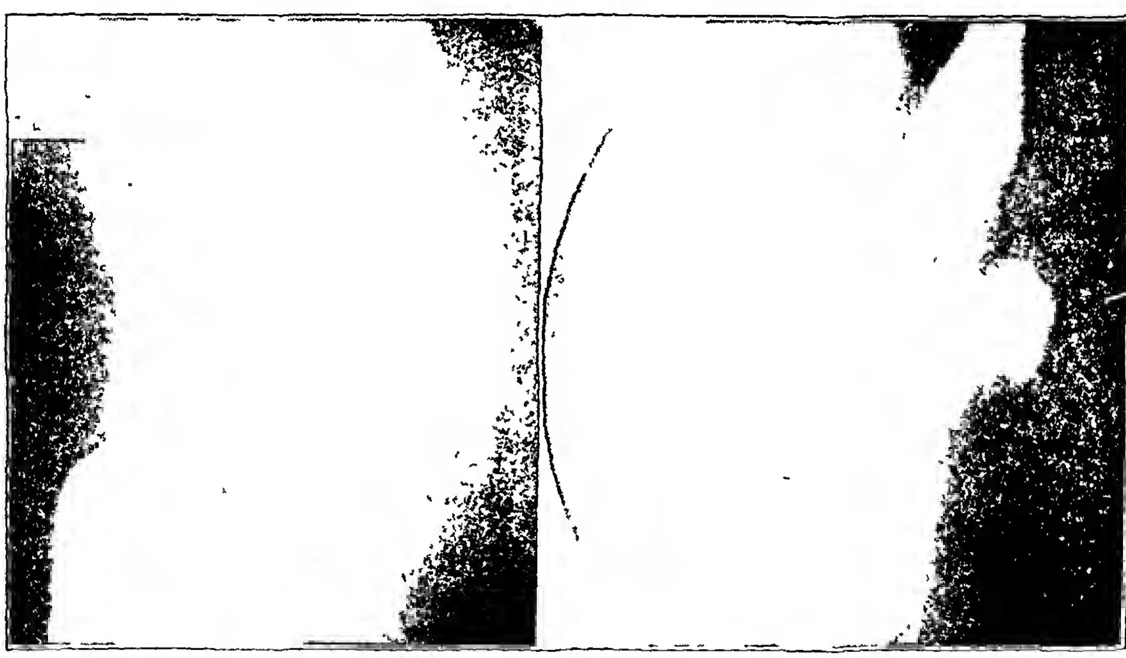

Fig. 2-A Fig. 2-B

Fig. 2-A: Lateral view of right wrist, demonstrating normal position of pisiform.
Fig. 2-B: Lateral view of left wrist, demonstrating dislocation of pisiform.

process of lifting a heavy object. Perhaps this bone has a tendency to become dislocated, since it was never intended to function in man as part of the mechanism of lifting. In man the hand is no longer a means of locomotion and, therefore, the carpal bones have undergone changes to conform to the new functional demand. Bizarro points out that the pisiform, which is the heel of the hand in the non-aquatic vertebrate, has become a regressive structure in man. An additional factor which should be taken into consideration is that one invariably flexes the wrist while lifting, which tends to draw the pisiform away from the triangular bone.

Clinically, following a dislocation, the pisiform is painfully displaced from its normal site, leaving a depression. Flexion and adduction may be painful, and there may be exaggerated mobility of the bone. The diagnosis can be confirmed by roentgenograms, with

the ulnar side of the wrist placed against the plate in about 15 degrees of supinated rotation. One must bear in mind that in an acute or recurrent dislocation the bone may return to its normal position, producing a negative roentgenogram. In the chronic case, where the patient complains of pain in the volar aspect of the wrist with a sensation of "giving way" upon lifting, duplication of the etiology may confirm the supposed diagnosis, as demonstrated in the case report.

CASE REPORT

The patient, a nineteen-year-old white male, entered the office with the complaint that he was unable to do heavy lifting, because of pain in the volar aspect of his left wrist "when something jumped out of place". When this happened, he stated, working the wrist up and down caused it "to jump back into place".

He experienced repeated episodes for nearly six years, dating back to an episode of acute pain in the wrist when he was lifting a heavy piece of lumber. A friend "snapped" his wrist, which seemed to correct the difficulty. He returned to work with moderate pain in the wrist, which subsided in time.

In the past four years he had been examined by two physicians, but nothing was found clinically or by roentgenogram, and the patient was discharged without treatment. During the course of such observation his wrist was put in a cast for three weeks to relieve a possible tenosynovitis.

Quite discouraged, he entered the office with this complaint. Clinically, the examination was essentially negative. He was asked if he could make this "something" jump out of place. He forcibly flexed and dorsiflexed while deviating his hand ulnarward. After fifteen minutes he suddenly exclaimed: "There, it happened again". Roentgenograms (Figs. 1-A, 1-B, 2-A, and 2-B) were taken, confirming the clinical impression. Pain was present across the volar aspect of the wrist, especially in the area of the pisiform. The bone was displaced distally, leaving a depression at its normal site. The wrist could be gently flexed and dorsiflexed without the bone being relocated. The patient forcibly flexed the wrist and reduced the displacement. It was found impossible to dislocate it with direct forceful digital pressure, even though there was a moderate degree of mobility of the bone.

FIG. 3

Lateral view, after removal of the pisiform.

The pisiform was shelled out surgically (Fig 3) through a transverse incision directly over the bone. The space occupied by the pisiform was closed so as to maintain the continuity of the flexor carpi ulnaris with the pisohamate and pisometacarpal ligaments. Four weeks after operation the patient resumed heavy labor; he had no discomfort, and a full range of motion was possible. He was seen six months later; at that time the result was perfect.

TREATMENT

In an acute dislocation with the wrist in flexion, the bone should be manipulated into place. An anterior molded plaster splint should be applied, with the wrist in dorsiflexion (30 to 40 degrees) and radial deviation for eighteen to twenty-one days. This position rigidly fixes the pisiform. In an acute case where the disability remains after splinting, or in a chronic case, surgical excision is recommended.

SUMMARY

1. Dislocation of the pisiform is rare. Volar pain in the wrist with the sensation of "something going out of place" may indicate a dislocating pisiform.
2. Dislocation of the pisiform is caused either by muscular violence or direct injury.
3. The pisiform is a regressive structure in man, but forms the heel of the hand in the non-aquatic vertebrate.
4. In acute cases of dislocation which do not respond to splinting, and in chronic

cases, surgical excision is indicated. Removal of the bone in no way interferes with the normal function of the wrist.

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COMPRESSION OF THE SPINAL CORD DUE TO DIRECT EXTENSION FROM A TUBERCULOUS PULMONARY ABSCESS

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Compression of the spinal cord by a tuberculous abscess in conjunction with tuberculous spondylitis is a well-known entity. The usual beginning of such a lesion is a focus in the body of one or more vertebrae, with the resultant abscess formation, which protrudes posteriorly through the intervertebral disc and causes pressure on the posterior longitudinal ligament. The abscess may also perforate this ligament and gain access to the canal.

Tuberculous spondylitis has always been considered a secondary lesion, due to a lymphatic extension or to a blood-borne infection. Tuberculous abscesses arising from the upper thoracic spine have frequently been known to rupture into the pleural cavity or into the lung. While tuberculous joints may become involved by direct extension from adjacent tissues, such as infected tendon sheaths or bursae, direct extension to the spinal canal and its contents from an adjacent focus is exceedingly rare.

A comprehensive review of the literature has disclosed very little mention of such a process. Alpers and Palmer reported one case in 1934, which was practically identical to the first case in this paper. Eaton and Rogers, in 1938, also reported one case of transverse myelitis, caused by pressure from a lung abscess. With the exception of these instances, no reports have been found.

The following two cases of compression of the spinal cord as a result of direct extension from a pulmonary lesion, without the usual picture of Pott's disease, presented a true diagnostic problem. It is usually felt that a destruction of the pedicle shadows, as seen in the roentgenograms of the first case, is the result of a tumor of intraspinal origin, rather than the result of an infectious lesion from without.

CASE 1 (No. 1753). R. A., a thirty-year-old white male, was admitted to the sanatorium on December 9, 1943. He stated that in July 1942 he had suffered an attack of pleurisy on the right side. Since that date, he had been forced to seek a lighter type of work. In July 1943, he consulted a physician, who made a diagnosis of tuberculosis of the right lung. On July 29, 1943, a right pneumothorax was induced, but the patient's condition became progressively worse. On November 17, 1943, he noticed a sense of weakness in the left leg, associated with numbness, which became progressively worse. About two weeks later, he noticed similar symptoms in the right lower extremity. On admission, the examination revealed complete spastic paralysis of both lower extremities. The deep reflexes of the upper extremities were hyperactive, and the knee jerks and ankle jerks were each four plus. The Babinski sign was present bilaterally, and there was sustained ankle clonus on both sides. The abdominal and cremasteric reflexes were absent. There was some hypoaesthesia below the nipple line, with tenderness at the level of the spinous processes of the third and fourth thoracic vertebrae.

The laboratory findings showed the Kahn reaction to be negative. The sedimentation rate was nineteen millimeters in fifteen minutes and twenty-six millimeters in thirty minutes. The stomach washings were positive for the tubercle bacillus. Otherwise, the routine tests were normal. A spinal puncture revealed clear fluid with an initial pressure of twenty-four centimeters. There was no rise or fall of pressure after compression of the jugular veins.

Roentgenograms showed destruction of a portion of the third and fourth ribs on the right, posteriorly, at the juncture with the spine, and a destruction of the pedicle shadows of the third and fourth thoracic vertebrae on the right (Fig. 1-A). However, there was no roentgenographic evidence that this patient had true Pott's disease.

It was obvious that a destructive lesion of some form was present at the level of the third and fourth thoracic vertebrae. An exploratory operation, performed shortly after admission, showed partial destruction of the lamina of the third thoracic vertebra on the right side. Some of this tissue was removed from between the second and third laminae for frozen-section study. This tissue was typical tuberculous granulation tissue. It was apparent that the patient had a tuberculous lesion, involving the spinal cord.

The patient died on February 27, 1944, and a complete autopsy was performed. The essential findings were a cavity in the base of the right upper lung lobe, extending posteriorly through both pleural layers into the body wall. A tuberculous caseous tract followed along the third and fourth ribs, destroying a portion of each of these ribs and also the pedicles of the third and fourth thoracic vertebrae on the right side. It extended through the intervertebral foramen into the spinal canal and enveloped the spinal cord (Fig. 1-B). The cord was irregularly compressed by a caseous mass which invaded the dura. The cord above and below this lesion was normal.

These findings demonstrate very clearly that a tuberculous transverse myelitis can occur as a result of direct extension from an adjacent focus.

CASE 2 (No. 1981). J. L., a twelve-year-old Mexican boy, entered the sanatorium on June 2, 1944, because of pulmonary tuberculosis. Shortly after admission a large cold abscess developed on his back to the right of the mid-line, at the level of the upper thoracic spine. The pus was aspirated on frequent occasions, and the tubercle bacillus was found in this material. Repeated roentgenograms of the thoracic spine failed to show any evidence of destruction of the vertebrae (Fig. 2-A), as is characteristic of tuberculous spondylitis.

In March 1946, the patient began to show signs of paraplegia. The lower extremities eventually became completely paralyzed, with an increase in the deep reflexes and an absence of the superficial reflexes. The Babinski sign was present. There was loss of sensation below the level of the fifth thoracic vertebra. The patient died on June 12, 1946, and again a complete autopsy was performed.

The essential autopsy findings were as follows: The left lung was free in the pleural cavity; the right lung was adherent throughout, especially at the apex, where there was a dry, caseating subpleural sinus

Fig. 1-A

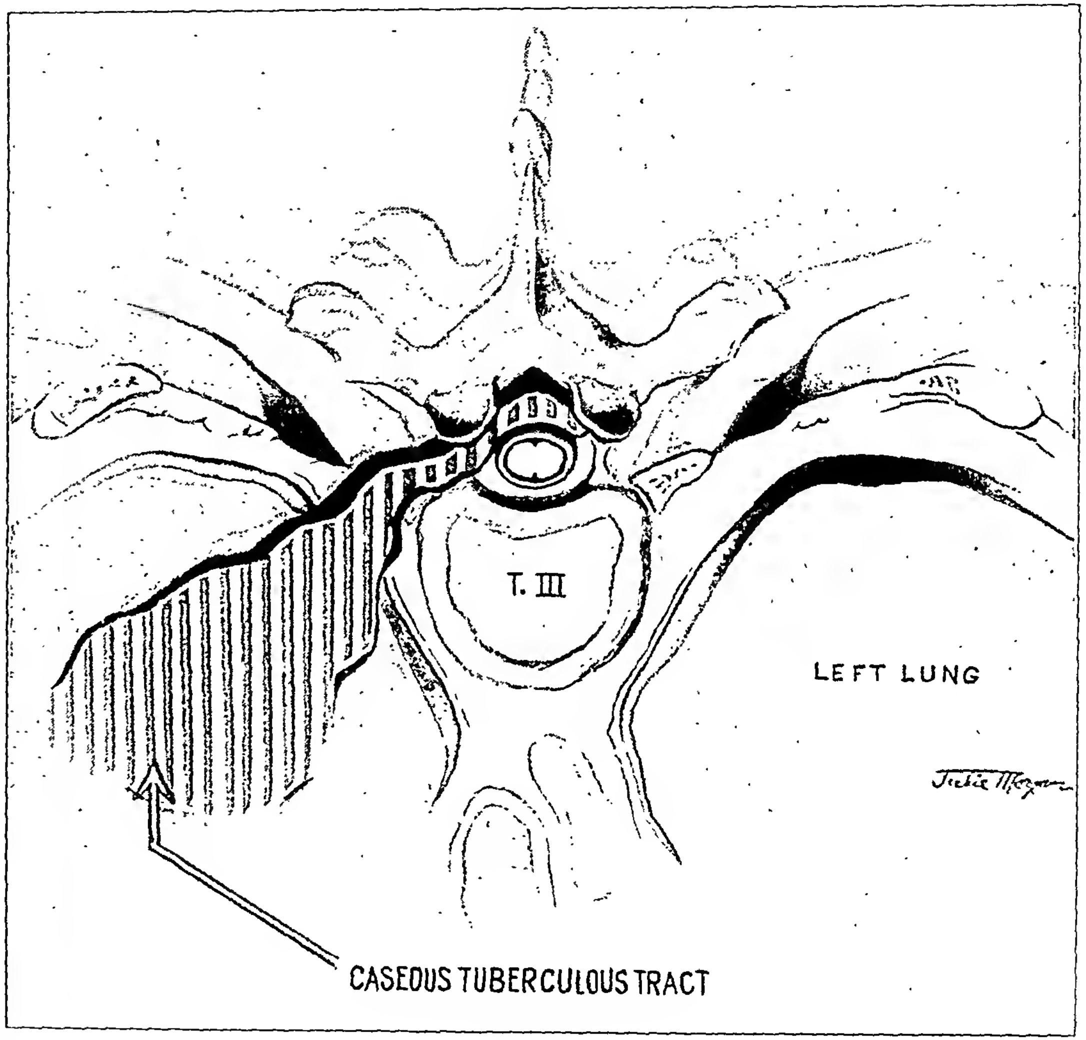

Fig. 1-B

Fig. 1-A: Case 1. Showing destruction of a portion of the third and fourth ribs on the right, and the pedicle shadows of the third and fourth thoracic vertebrae on the right.

Fig. 1-B: Diagram showing tuberculous cavity in right lung, which has perforated through the pleura and extended along the body wall and into the spinal canal by way of the intervertebral foramen.

FIG. 2-A

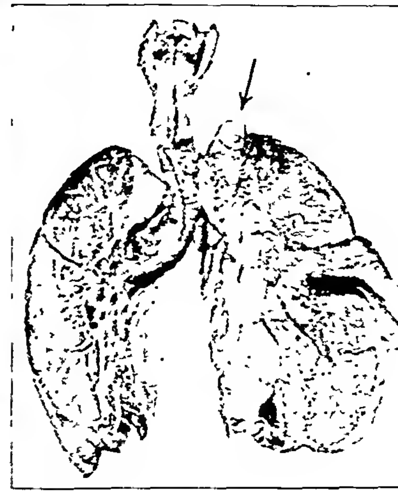

FIG. 2-B

FIG. 2-C

Fig. 2-A: Case 2. A lateral roentgenogram of the thoracic spine, which shows no evidence of a destructive lesion of the vertebral bodies.
Fig. 2-B: Postmortem specimen of lungs, showing tuberculous caseous tract.
Fig. 2-C: Microscopic section shows caseous mass in upper portion, marked thickening of the dura, and pressure on the spinal cord.

(Fig. 2-B). This sinus extended laterally around to the back, involved the spinous processes of the third, fourth, and fifth thoracic vertebrae, extended through the intervertebral foramina into the canal, and caused compression of the spinal cord at this level (Fig. 2-C). On the thoracic surface of the spinal cord was a large tuberculous caseous mass which had not invaded the cord, but which had caused a marked thickening of the dura and had thus compressed the cord.

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MORTON'S METATARSALGIA

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This report is based on the clinical and pathological findings recorded in twenty cases of Morton's metatarsalgia, treated at the Charlotte Memorial Hospital during the past three and one-half years.

As long ago as 1876, Morton of Philadelphia reported that certain cases of metatarsal pain fell into a specific group. This syndrome of plantar metatarsal pain has come to be known as Morton's toe. Morton's original explanation was that this condition was due to a disturbance in the fourth metatarsophalangeal articulation, or possibly to pinching of the digital branches of the lateral plantar nerve between the fourth and fifth metatarsal heads, because of the great mobility and play of the fifth metatarsal.

Betts described this syndrome in 1940 as one associated with a change in the fourth plantar digital nerve. He ascribed the condition to a stretching and irritation of this nerve, which differs anatomically from the other plantar digital nerves in that it has a double origin,—one branch from the medial plantar nerve and one branch from the lateral plantar nerve. After anastomosing, the nerve, as described by Baker and Kuhn, "continues distally between the flexor brevis muscle and the plantar aponeurosis just proximal to the heads of the metatarsals, where it penetrates the aponeurosis and passes beneath the transverse metatarsal ligament. Just distal to the ligament it turns upward into the web space between the third and fourth toes, where it divides into the medial and lateral branches which supply the adjacent sides of the third and fourth toes."

Betts theorized that, because this nerve was thicker and more fixed, it was thus prone to stretching and irritation during dorsiflexion of the foot.

McElvenny brought this syndrome, with its modern etiological conception, before the medical profession in 1943. He found that surgical treatment of this syndrome—that is, excision of the tumor between the third and fourth toes at the plantar level of the bases of the proximal phalanges—gave relief.

In 1944, Baker and Kuhn of Duke University reported eighteen dissections on cadavera and found the anatomical relationship previously reported by Betts. They also reported a series of fourteen operations on eleven patients (three of the patients had bilateral pain).

Authors of textbooks of anatomy describe the medial plantar nerve as terminating in four plantar digital nerves, the first supplying the medial side of the great toe, the second supplying the opposing faces of the big toe and the second toe, the third supplying the opposing faces between the second and third toes, and the fourth supplying the opposing faces of the third and fourth toes. The lateral plantar nerve ends in two terminal branches, the medial one supplying the interval between the fourth and fifth toes and the lateral one supplying the lateral portion of the little toe. Thus the dissections by Betts and by Baker and Kuhn show more clearly why the interspace between the third and fourth metatarsal heads, supplied by the fourth plantar digital nerve (which is composed of branches from both lateral and medial plantar nerves), is the site of the majority of these irritative lesions of the plantar digital nerves.

In reviewing the records of the twenty cases treated at Charlotte Memorial Hospital, we find that the patients usually have had the symptoms for some time, and have already tried various measures to relieve the pain, without success. The pain is described as being localized near the fourth metatarsal head, sometimes radiating up the leg. It is often so intense that the patient has to take off his shoe to rub or press the painful area. In

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addition, tingling and numbness of the third and fourth toes may be noted. Examination reveals a normal-appearing foot. There is localized tenderness on pressure in the region between the third and fourth metatarsal heads, sometimes more intense on the plantar surface and sometimes on the dorsal surface. Sensory changes may be present in the third and fourth toes. A nodule can occasionally be palpated deep in the third web space. Roentgenograms fail to show evidence of abnormality.

In this series of twenty cases, there were no complications. Two patients had delayed healing of the incision, but made uneventful recoveries. There have been no untoward consequences as a result of sectioning this nerve, and no painful neuromata; no trophic disturbances have developed.

There is little variation in the clinical symptoms presented, so that it is possible to predict with fair accuracy that a patient with typical symptoms will receive relief only from operation.

Because of the similarity of these cases, only one is summarized to illustrate this condition.

W. E. P. The patient was a white housewife, twenty-six years of age. Exquisite, lancinating pain had been present in the region of the third and fourth toes of the right foot for at least a year before the patient was seen. There was tingling of the third and fourth toes. No relief had been obtained from changes of shoes, or from the use of metatarsal pads, arch supports, or metatarsal bars.

Examination of the foot showed no alteration of normal contour. There was tenderness on firm pressure in the area between the third and fourth metatarsal heads, with slight radiation and numbness on the outer aspect of the third toe and the medial aspect of the fourth toe. A roentgenogram of the fore part of the foot was essentially negative.

An operation was performed on November 8, 1943. With the use of sodium pentothal anaesthesia and an Esmarch bandage, a small longitudinal incision was made on the dorsum of the foot, over the interspace between the third and fourth metatarsal heads. Upon separation and dissection of the fatty tissue, the fourth plantar digital nerve was found to have a nodular enlargement as it emerged from the plantar fascia. This was resected, with about half an inch of the nerve.

The postoperative course was quite satisfactory. The patient was dismissed from the Hospital on November 13, with a protective dressing. On November 18, when the sutures were removed, the wound had healed, and the patient was given a split shoe for walking. She was apparently completely relieved of her symptoms.

On February 2, 1947, the patient reported to the office with a complaint of low-back difficulty. Inquiry was made about the foot, and the patient could not remember at first which foot had been operated upon. She stated that she was completely free of symptoms, that she carried on normal housework, and had had two children in the interval since her operation.

PATHOLOGICAL FINDINGS

The gross examination of all the specimens revealed a marked fusiform thickening of the plantar nerve. No attempts were made to determine accurately the diameter, since it was obvious that a good deal of fat and connective tissue had been removed with the nerve. A definite line of cleavage between the tumorous swelling of the nerve and the surrounding tissue could not be detected.

Histological sections showed similar changes in all cases, consisting of massive thickening of the connective-tissue elements of the nerve. Extreme fibrosis and hyalinization of the perineurium were found consistently in all instances, but in most of them the process also extended into the endoneurium, thus separating nerve bundles as well as nerve fibers from each other (Figs. 1, 2, 3, and 4). Perineurium and epineurium blended imperceptibly into the adjacent connective tissue. Attempts to demonstrate changes in the nerve fibers by myelin-sheath stains did not yield conclusive evidence, although changes were noted which were suggestive of degeneration. Fat-laden macrophages were absent.

The increased amount of collagenous connective tissue was characterized by relative paucity of nuclei, and was not suggestive of new growth. There was no evidence of proliferation of Schwann's cells. Inflammatory infiltration was absent, but occasionally iron-

pigmented macrophages were found, indicating previous hemorrhage, possibly due to trauma.

Fig. 1
Showing spindle-shaped enlargement of nerve (low-power magnification).

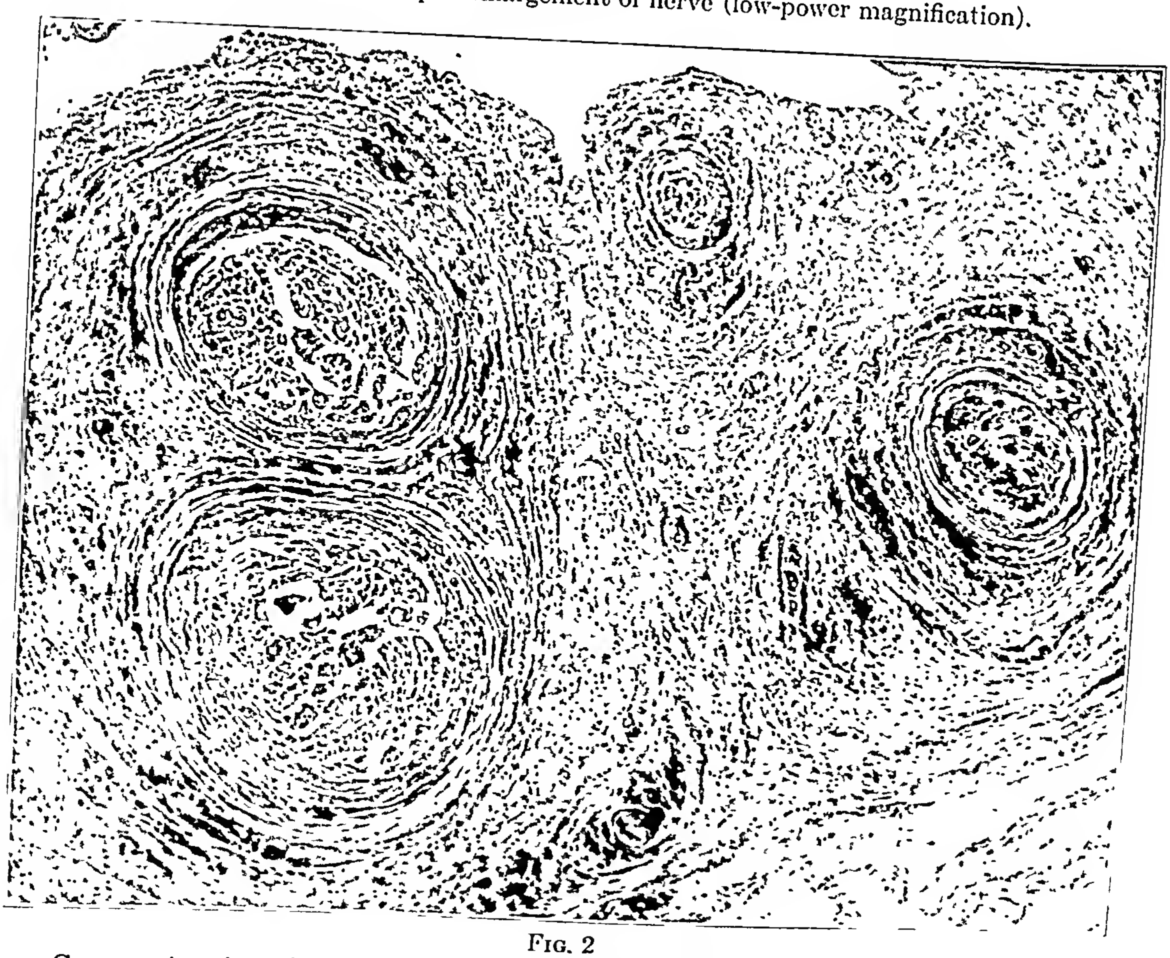

Fig. 2
Cross section through nerve, showing extreme thickening of perineurium (low power).

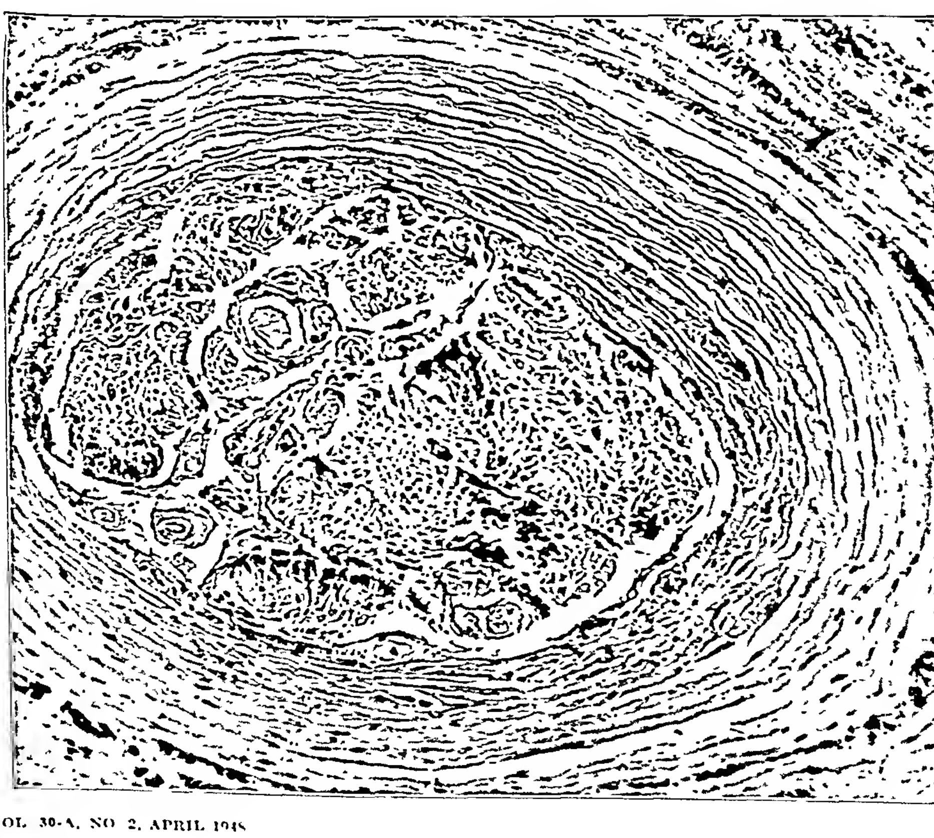

Fig. 3

Cross section, showing thickening of perineurium and some thickening of endoneurium (medium-power magnification).

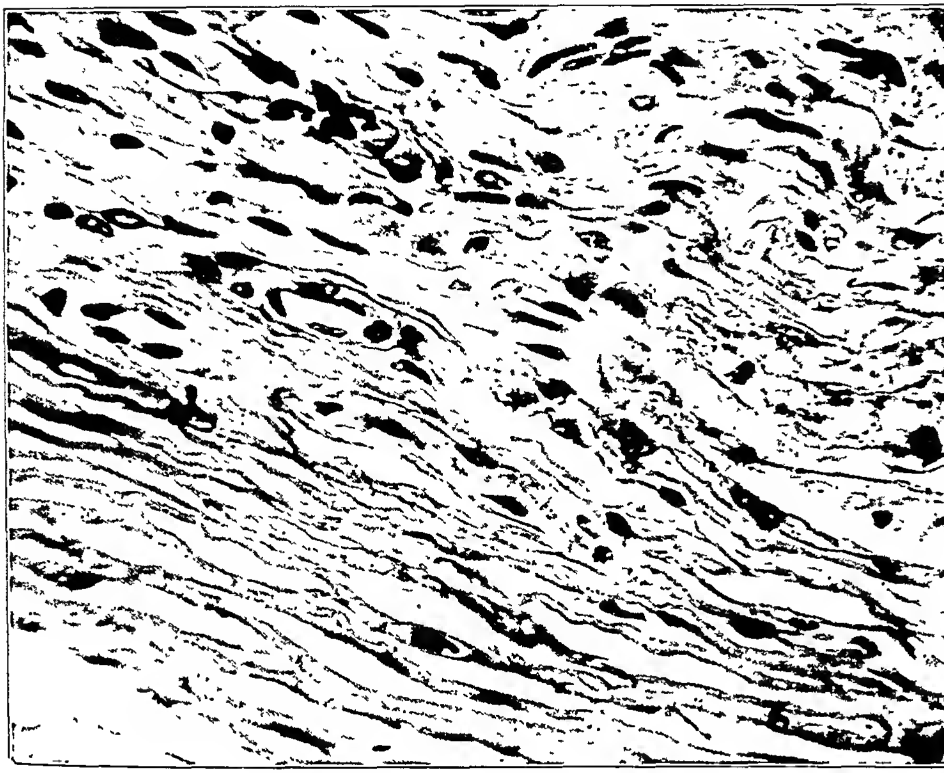

Fig. 4

Showing deposit of hyaline material in perineurium and the rather indistinct border of perineurium and nerve tissue (high-power magnification).

CONCLUSIONS

The authors' findings agree essentially with those of Baker and Kuhn. We did not find changes which could be interpreted as evidence of active proliferation of either nerve tissue or connective tissue. The deposition of hyaline and collagenous material in itself accounts for the enlargement, in our opinion. We believe, therefore, that the process is essentially degenerative in nature, trauma being its most probable cause.

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THE pH OF THE SYNOVIAL FLUID IN THE ANAESTHETIZED DOG UNDER TREATMENT WITH METRAZOL OR INSULIN*†

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Exchanges of electrolytes between the synovial cavity, blood, and interstitial fluids depend upon changes of electrolyte concentration of these fluids, and also upon autonomic activation of the vascular system in surrounding tissues [2,3]. Muscle activity results in lowering the pH of synovial fluid by the formation of acid metabolites. In periods of rest following muscle activity, the pH returns approximately to the original resting level, the rate of recovery depending upon the state of the circulation as determined by autonomic regulation.

As part of a systematic study of the effects of autonomic and central controls over synovial fluid, the investigation described here was planned to determine the pH of synovial fluid *in vivo* after the administration of metrazol or insulin. The purpose is to define the effects of the resulting convulsions on the pH of the blood and synovial fluid in animals with intact nervous systems. The pH changes are related to systemic conditions in both the pre-convulsive and actively convulsive phases of the drug action. The comparison of blood and synovial-fluid pH indicates the nature of electrolyte exchanges between these fluids in the two phases.

* The expenses of this investigation were in part defrayed by the Arthritis Research Project of the University of Illinois.

† A preliminary report of this work was presented before the American Physiological Society, May 20, 1947; and an abstract was published in *Federation Proceedings*, 6: 211, 1947.

TABLE I

METRAZOL CONVULSIONS IN DOG NO. 3 *

Time (*Minutes*)	pH in Left Knee Joint	pH in Left Femoral Vein
2		7.49
3		7.47
4		7.46
4½		7.46
5½		7.50
6		7.46
8	7.41	
10	7 34	
10½	7.34	
12		7.46
14		7.44
16	7 39	
16½		7.46
18	7.38	
19½		7.46
21	Injection of metrazol (6 cubic centimeters of 10 per cent. metrazol in sodium citrate)	
21½	7 40	
22½	7 40	
23	Convulsions	
26½	7 27	7.34
27½		7.30
29	7.20	
30		7.33
32	7.17	
34		7.30
35	7.11	
38	7.10	
40	7 14	
45		7 35

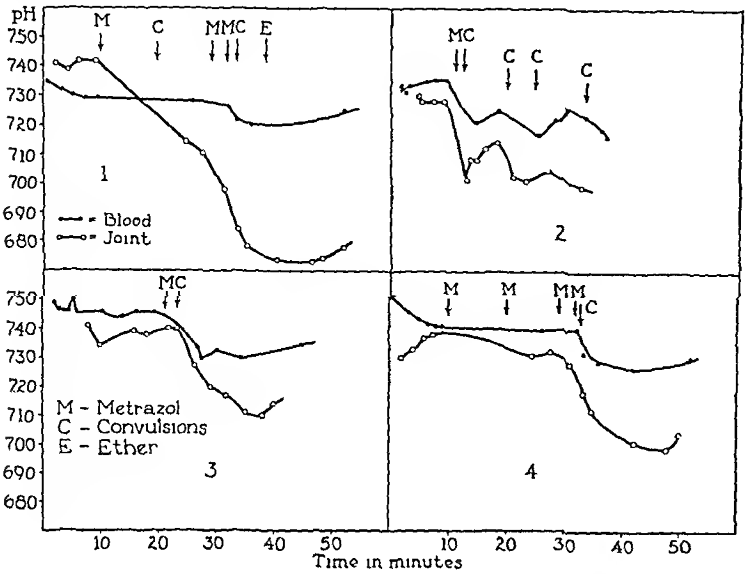
* This dog weighed 22 pounds; nembutal was used as anaesthetic.

EXPERIMENTS

The method of determining *in vivo* the pH of blood and synovial fluid in dogs has previously been described in detail[2,3]. Needle reference electrodes were inserted into an exposed femoral vein and into the knee-joint cavity on the same side. Capillary glass electrodes were immediately inserted into the needles, and readings of electromotive force were made over a period of ten or fifteen minutes until several consecutive readings agreed within two or three millivolts for any given pair of electrodes. Metrazol or insulin was then injected into the heart, and pH readings were made at frequent intervals in the femoral venous blood and in the synovial fluid on the corresponding side. These were continued through both the pre-convulsive and convulsive stages for each of the two drugs. All dogs were anaesthetized with nembutal.

Complete records for two different dogs, one treated with metrazol and one with insulin, are presented in Tables I and II. Results are illustrated graphically in Figure 1 for metrazol, and in Figure 2 for insulin.

solution, was injected in sufficient quantity to cause convulsions. In several instances two or three injections were required, the first one sometimes resulting only in muscle tremors or increased muscle rigidity. Results on six of the animals are presented in Figure 1, *1*. In every experiment, after the onset of convulsions, there was a sharp fall in pH in the synovial fluid and a much less pronounced fall in blood pH. In the pre-convulsive stages, after the injection of the drug, there appeared to be no significant changes in the pH of either fluid. However, immediately after the beginning of convulsions, marked changes



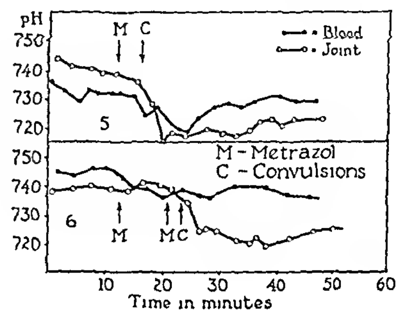
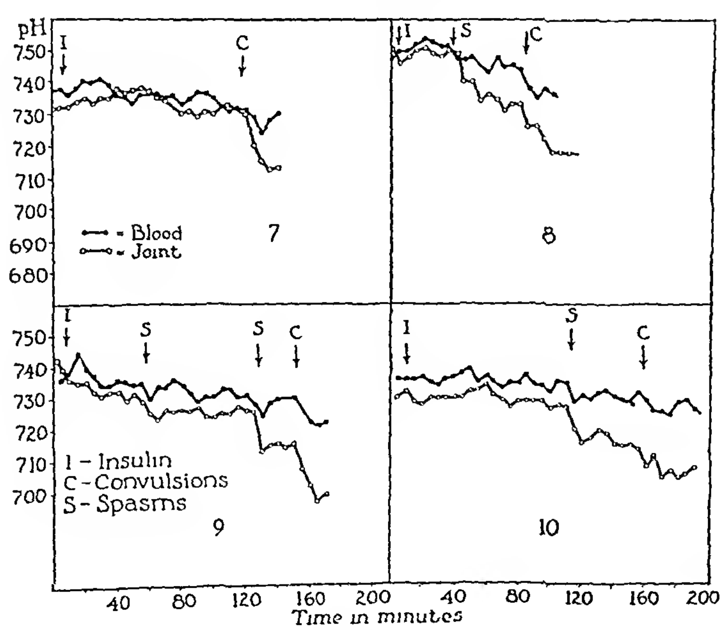


Fig. 1

Responses to metrazol. The maximum depression of the pH usually tended to appear later in the synovial fluid than in the blood; it was of greater magnitude and returned to the previous level more slowly.

in the pH occurred in the direction of increased acidity. In most of the cases, the blood pH varied within a range of about 0.15 after the injection of metrazol, while the synovial-fluid pH was observed to vary over two to four times that range. There was no marked parallelism between the two.

In Table III, the results for six animals are shown, expressed in a different manner. The resting pH is given for both blood and joint fluid, together with the pH at the maximal displacement and the time of the maximal displacement, measured from the first injection. In most of the cases the maximal change of joint pH was about two or three times as large as the maximal change of blood pH, and it usually occurred at a later phase of the convulsions. The results



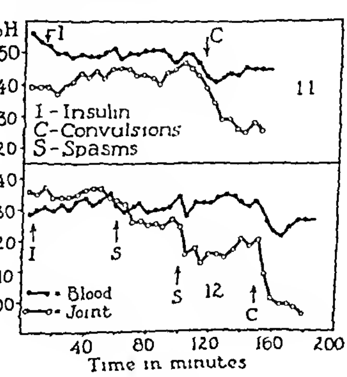


Fig. 2

The responses to insulin were of less magnitude in both fluid and blood, and tended to be parallel. Also, the pH was less regular in both sites. Insulin convulsions were less effective than those due to metrazol.

TABLE II

Insulin Convulsions in Dog No. 7 *

Time (*Minutes*)	pH in Right Knee Joint	pH in Right Femoral Vein
1	7.24	
2	7.29	
3		7.43
4		7.39
5	7.33	
6		7.37
8	7.34	
10	7.32	
12		7.39
13		7.38
14	7.32	
15	7.32	7.38
20	7.32	7.38
21½	Injection of insulin (200 units)	
25	7.32	7.36
30	7.34	7.38
35	7.35	7.41
40	7.33	7.40
45	7.35	7.41
50	7.35	7.39
55	7.38	7.36
60	7.36	7.35
65	7.38	7.33
70	7.38	7.36
75	7.37	7.36
80	7.35	7.36
85	7.34	7.35
90		7.36
95	7.30	7.33
100	7.31	7.35
105	7.29	7.37
110	7.31	7.37
115	7.30	7.35
120		7.32
125	7.33	7.31
130		7.32
130	Onset of convulsions	
135	7.30	7.31
140	7.20	7.29
145	7.15	7.24
150	7.12	7.28
155	7.12	7.30

* This dog weighed 25 pounds; nembutal anaesthesia was used.

plotted in Figure 1, *1* indicate that the joint pH progressively became more acid than the blood pH.

2. *Insulin*

The effects on blood and joint pH of convulsions induced by insulin were determined on six dogs, anaesthetized with nembutal. The results of these experiments, presented graphically in Figure 2, show the variations of pH over a period of time, including a comparatively long pre-convulsive period and a period of active spasms and convulsions. After administration of insulin, as also following injection of metrazol, muscle activity, manifested in spasms or convulsions, resulted in lowering of the pH of both blood and joint fluid. The variations of joint pH were generally greater than those of the venous blood.

TABLE III

DISPLACEMENT OF pH OF BLOOD AND OF JOINT FLUID AFTER INJECTION OF METRAZOL

Dog No.	Blood * pH		Joint pH		Time from Injection of Drug to Maximal Displacement	
	Resting	Displaced	Resting	Displaced	Blood (*Minutes*)	Joint (*Minutes*)
1	7.29	7.20	7.41	6.73	26	36
2	7.36	7.16	7.28	6.99	14	21
3	7.46	7.30	7.40	7.10	7	17
4	7.40	7.27	7.38	7.00	32	38
5	7.32	7.19	7.39	7.15	12	8
6	7.46	7.37	7.39	7.19	8	26

* Femoral vein.

There was little tendency for the joint pH to follow closely the variations of blood pH. It was observed that pH changes of both fluids were most pronounced whenever vigorous muscle movements occurred during spasms or convulsions.

As in the series of metrazol experiments, it was observed that the range of variability of synovial-fluid pH was greater than that of blood pH. During insulin convulsions, the blood pH rarely fell more than 0.2 below the resting level. The pH of synovial fluid during severe convulsions often deviated from the resting value by about 0.4 or 0.5 unit. On the whole, in insulin convulsions, there appears to be a more distinct parallelism between the curves of blood pH and joint pH than in the experiments with metrazol. With neither drug, however, can any highly correlated parallelism be observed. There was a tendency in each of the experiments with insulin for both pH curves to pass through a series of roughly corresponding maxima and minima, the sharpest minima occurring immediately after periods of muscle spasms or convulsions. The general trend, plotted over a period of two to three hours, however, showed a tendency for the joint pH to become considerably more acid than the blood pH. This tendency is similar to that observed in the metrazol series, where, however, the effects were more acute and appeared in a much shorter time.

DISCUSSION

In an earlier investigation it was found that, following femoral-nerve stimulation and muscle contraction, the pH of the synovial fluid and that of the femoral venous blood fell immediately; the blood pH recovered in a few minutes, while the pH of the joint fluid often remained acid for a much longer time. These effects are in contrast to those observed after the intravenous injection of dilute acids, when the blood pH rapidly decreased, passing through a minimum and approaching the original level within a few minutes. The pH of the synovial fluid, however, decreased much more slowly and by a smaller amount, reaching a minimum considerably later and recovering much more slowly than the blood pH. It was pointed out that acid metabolites, produced in the tissues, were transferred to synovial fluid more rapidly than acids injected into the circulation. This fact points to a close relationship between synovial fluid and tissue fluid. The capillary circulation also must be considered to exchange water and electrolytes with both synovial fluid and tissue fluid. These exchanges would depend not only on differences in concentrations of various diffusible ions and of the colloids in the fluids, but also on membrane permeabilities and on hydrostatic pressure gradients. A considerable number of physiological, as well as physicochemical, factors must thus be involved in the situation. These considerations agree well with the conclusions reached by Bauer, Ropes, and Waine.

The results described in the series of experiments with metrazol and insulin are consistent with this conception of the problem. Acid metabolites produced during muscle

activity appear to have been transferred rapidly to the joint cavity without the mediation of the capillary circulation. The joint pH thus fell rapidly after severe muscle spasms or convulsions. This effect is in contrast with the previously observed delayed response of joint pH to dilute acids injected into the circulation. The relatively large pH changes in the synovial fluid, as compared with those of the femoral vein, also indicate that the synovial-fluid pH is determined by electrolytes produced in the active tissues, which are almost immediately transferred to the joint cavity. Recovery of the pH after displacement depends upon circulatory removal of the accumulated metabolites during the resting phase.

In the observations that have been reported, the rate of recovery in the resting phase is invariably slower than the rate of pH displacement in the periods of muscle activity. These observations thus agree with earlier ones which indicated that the joint pH is more rapidly lowered by acids produced in the tissues than by acids injected into the circulation. Diffusion of hydrogen ions between the joint cavity and the capillaries appears to be a slower process than diffusion between the tissue fluids and the joint cavity.

SUMMARY

This paper reports the results of alterations in the pH of synovial fluid and of blood of dogs anaesthetized with nembutal, in response to agents producing extreme muscle activity.

The intravenous administration of metrazol, in doses producing convulsions, resulted in a more pronounced decrease in the pH of synovial fluid than in that of blood. This difference was progressively developed to a maximum stage somewhat later than in blood.

The injection of insulin produced similar, but less pronounced, results, although the graphs were less smooth and regular and there was better correlation between the alterations of pH in the two fluids.

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MECHANICAL RETARDATION OF BONE GROWTH

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In a previous paper[1], a method was presented for the retardation of bone growth by means of a loop of wire, encircling the epiphyseal cartilaginous plate. The loop of wire prevented the epiphysis from being advanced forward, as occurs normally after the laying down of new bone in the metaphyseal-epiphyseal region. It was found that the restraining power of the wire loop did not permanently destroy the proliferative properties of the columns of cartilage cells of the epiphyseal plate, and bone growth was resumed after the release of this hindering force. It was also shown that a loop of wire around one side of an epiphyseal cartilaginous plate restricted growth on the side of its insertion, with a resulting asymmetrical growth at that articular end of the bone.

Although the cartilaginous plate was restrained only temporarily, the question arose as to whether or not there was any loss in relative activity as compared with the normal rate of growth. The question was also asked as to whether or not premature closure of the plate might take place, due to the temporary mechanical brake.

In an endeavor to solve some of the problems of growth, a series of experiments were performed on growing dogs. In this series, staples were used instead of the wire loop. In one set of experiments, the staples were inserted on both sides of the plates and were allowed to remain in position until the termination of the experiment. In another series, the staples were removed after the lapse of a certain length of time, and growth studies were continued until the end of the experiment. In other experiments, staples were inserted on only one side of the cartilaginous plate.

Some interesting findings were obtained from these experiments, which may be of practical significance. These findings will be discussed after the results of the operations have been reported.

I. STAPLES ON BOTH SIDES OF EPIPHYSEAL CARTILAGINOUS PLATE

Experiment 1, Dog 4

Method: Staples were inserted laterally and medially across the distal epiphyseal plate of the right radius.

Result: Forty-six days later, the growth of the normal left radius was 2.2 centimeters. The growth of the bone on the side operated upon was 1.4 centimeters. The loss of growth was 0.8 centimeter.

Experiment 2, Dog 5

Method: A staple was driven across the distal epiphyseal plate of the left femur, both laterally and medially.

Result: One hundred and forty-one days later, the growth of the normal femur was 1.8 centimeters. The growth of the femur which had been operated upon was 0.8 centimeter. The loss of growth was 1.0 centimeter.

Experiment 3, Dog 6

Method: A staple was placed on both the lateral and medial aspects of the proximal epiphyseal plate of the left tibia.

Result: Forty-five days later, there was 0.5 centimeter of difference between the length of the normal tibia and of that which had been operated upon. The staples had not been inserted very firmly.

FIG. 1

FIG. 2

Fig. 1: Experiment 4, Dog 7. Long staples were inserted on both the lateral and medial aspects of the epiphyseal plate. There was growth of 1.4 centimeters on the normal side and 0.5 centimeter on the side of the inserted staples.

Fig. 2: Experiment 5, Dog 1. Staples were inserted over the lateral and medial aspects of the distal epiphyseal cartilaginous plate. Growth on the normal side at the end of seventy-seven days was 3.2 centimeters; growth on the side which had been operated upon was 1.6 centimeters. There was no deformity at the articular surface. The staples were removed at the end of this period.

Experiment 4, Dog 7

Method: Staples were inserted both medially and laterally across the distal epiphyseal plate of the left femur.

Result: Two hundred and five days later, growth of the right femur was 1.4 centimeters. The growth of the femur which had been stapled was 0.5 centimeter. There was loss of growth of 0.9 centimeter (Fig. 1).

Summary of the Results with Bilateral Staples

There was an arrest of length growth in every case in which staples had been inserted on both sides of the epiphyseal cartilaginous plate. The amount of growth from the proximal epiphyseal cartilaginous plate was greater than one would anticipate from the normal ratio of 3 to 1. There is a possibility of compensatory growth from the non-arrested epiphyseal plate.

II. STAPLES INSERTED ON BOTH SIDES OF THE EPIPHYSEAL PLATE AND REMOVED LATER

Experiment 5, Dog 1

Method: Staples were inserted both medially and laterally across the distal epiphyseal plate of the right radius. They were removed at the end of seventy-seven days; observations were continued for 185 days (Fig. 2).

Result:

	At 77 Days	*From Removal of Staples to 185th Day*
Growth of normal radius.....	3.2 centimeters	1.1 centimeters
Growth on side which had been operated upon	1.6 centimeters	0.8 centimeter

After removal of the staples, the relative growth was 1.4 to 1; while before removal it had been 2 to 1. This was a considerable increase in growth rate, but it was not so active as the normal after removal of the restraining force.

Experiment 6, Dog 2

Method: Staples were inserted medially and laterally across the distal epiphyseal plate of the right radius. At the end of eighty-four days the staples were removed; the experiment was continued for 143 days.

Result:

	At 84 Days	*From Removal of Staples to 143rd Day*
Growth of normal radius	3.4 centimeters	0.7 centimeter
Growth on side which had been operated upon	1.9 centimeters	0.4 centimeter

There were signs of earlier ossification on the side which had been operated upon, suggesting an injury to the plate. This might account for the failure of increase in rate after removal of the restraining force.

Experiment 7, Dog 9

Method: Two staples were inserted on both the medial and lateral aspects of the distal epiphyseal cartilaginous plate of the right femur. They were removed at the end of eighty days. The experiment was continued until the one hundred and eighty-seventh day.

Result:

	At 80 Days	*From Removal of Staples to 187th Day*
Growth of normal bone	2.6 centimeters	0.9 centimeter
Growth of bone on side operated upon	1.4 centimeters	0.4 centimeter

There was a little acceleration in the rate of growth after removal of the staples. Considerable difficulty was experienced in removing the staples, with some injury to the bone in the region of the plate.

Experiment 8, Dog 8

Method: Two staples were inserted across both the medial and lateral aspects of the distal epiphyseal plate of the right femur. They were removed after ninety days, and the experiment was continued for 348 days.

Result:

	At 90 Days	*From Removal of Staples to 348th Day*
Growth of normal bone	3.5 centimeters	1.5 centimeters
Growth of bone on side operated upon	2.0 centimeters	1.0 centimeter

The rate of growth of 1.7 to 1 was increased to 1.5 to 1. The animal was near the end of the growth period at the time the staples were removed.

Summary of Results with Staples on Both Sides of the Plate, Subsequently Removed

There was an arrest of growth at the epiphyseal plate which had been operated upon, up to the time of removal of the staples. The rate of growth increased after removal of the staples, but it was not so rapid as the normal rate of growth. There is the possibility of injuring the plate when removing the staples, and of disturbance in circulation, which may hinder the function of the epiphyseal plate.

III. STAPLES PLACED ON ONLY ONE SIDE OF EPIPHYSEAL CARTILAGINOUS PLATE

Experiment 9, Dog 1

Method: Two staples were placed across the lateral aspect of the epiphyseal plate at the distal end of the left femur.

Result: Two hundred and fifty-nine days later there was a difference of 0.6 centimeter in length of the two bones; the loss was 1.3 centimeters during the first 100 days. The hip

became dislocated during the experimental period, which may explain the difference in rate of growth.

Experiment 10, Dog 2

Method: Two staples were placed across the lateral epiphyseal plate at the distal end of the left femur.

Result: Three hundred and six days later the growth of the normal medial and lateral condyles was 2.3 centimeters. There was only 2.0 centimeters of growth of the medial condyle and 1.5 centimeters of growth of the lateral condyle of the bone which had been operated upon. This represents a growth loss of 0.3 centimeter of the medial condyle and 0.8 centimeter of the lateral condyle of the femur which had been operated upon.

Experiment 11, Dog 3

Method: Two staples were placed across the lateral aspect of the epiphyseal plate at the distal end of the right radius. One staple was removed after eighty-four days; the experiment was continued for 202 days.

Result:

	At 84 Days	*At 202 Days*
Normal bone growth	4.0 centimeters	5.0 centimeters
Growth of bone operated upon		
Medial	2.9 centimeters	3.7 centimeters
Lateral	2.5 centimeters	3.1 centimeters

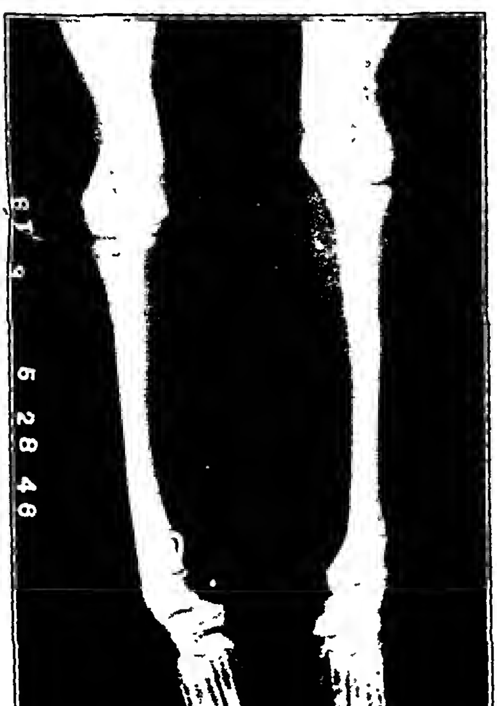

FIG. 3

FIG. 4

Fig. 3: Experiment 11, Dog 3. Staples were placed on the lateral aspect of the epiphyseal plate of the distal end of the right radius.

Growth of the normal bone at the end of eighty-four days was 4.0 centimeters. Growth on the medial side of the bone which had been operated upon was 2.9 centimeters; on the lateral aspect it was 2.5 centimeters. The staples had become displaced during the interval, allowing more growth from the distal end than would have occurred if they had remained in position. Notice the angulation of the articular surface and the difference in length between the normal bone and that which was operated upon.

Fig. 4: Experiment 12, Dog 3. A long staple was inserted over the lateral epiphyseal plate of the left femur. Roentgenograms of the dissected specimen show the loss of growth, and also the deformity of the articular surface of the lower end of the femur. (This roentgenogram has been reversed.)

The staples became displaced during the growth of the bone, but the retention was sufficient to hinder growth on both sides. As the staples became displaced, there was 1.0 centimeter of growth from the distal epiphysis (Fig. 3).

Experiment 12, Dog 3

Method: A long staple was driven across the epiphyseal plate on the lateral aspect of the distal end of the left femur. The duration of the experiment was 102 days.

Result:

	At 102 Days
Normal bone growth	2.4 centimeters
Growth of bone operated upon	
Medial	1.0 centimeter
Lateral	0.5 centimeter

The articular end of the bone which had been operated upon was widened. There was a loss of growth of the medial condyle of 1.4 centimeters, and a loss of growth of the lateral condyle of 1.9 centimeters (Fig. 4).

Experiment 13, Dog 5

Method: Three staples were placed across the lateral epiphyseal plate at the distal end of the right radius. Two staples were removed on the eighty-first day; the observation continued until the one hundred and eighty-eighth day.

Result:

	At 81 Days	*At 188 Days*
Normal bone growth	3.0 centimeters	3.8 centimeters
Growth of bone operated upon		
Medial growth	2.0 centimeters	2.3 centimeters
Loss	1.0 centimeter	1.5 centimeters
Lateral growth	1.8 centimeters	1.8 centimeters
Loss	1.2 centimeters	2.0 centimeters

The epiphyseal plate appeared to be undergoing premature closure.

Experiment 14, Dog 6

Method: Two staples were inserted on the medial side of the epiphyseal plate at the distal end of the right radius. Two sinuses developed, but they healed promptly.

Result:

	At 118 Days
Normal bone growth	2.5 centimeters
Growth of bone operated upon	
Lateral growth	1.9 centimeters
Loss	0.6 centimeter
Medial growth	1.4 centimeters
Loss	1.1 centimeters

Summary of Results with Unilateral Staples

Staples inserted on one side will prevent growth on that side. There will also be a retardation of growth on the opposite side, but to a lesser degree. There will be a diminution of the total length of the bone by staples inserted on one side.

COMMENTS

One of the important findings in this set of experiments is concerned with the insertion of staples on one side of the epiphyseal cartilaginous plate. There was a complete hindrance of growth on the side of their insertion. A marked loss in length growth was found on the opposite side as well, causing a decrease in the total growth of the entire bone as compared with the normal. In reviewing the original experiment with the use of a wire loop on one side of the plate, it was found that there was also a loss in total length; but the significance

of this result was not appreciated at that time. One should consider carefully the application of this principle, which was recommended at that time as a means of compensating for deformity due to unilateral overgrowth of a bone. In retrospect, it is obvious why there is a loss of length growth on the opposite side. The growth in length is caused by the laying down of new bone at the juncture of the metaphysis and epiphysis. This new bone pushes the epiphysis away as a block or cylinder of bone. The wire loop or staple, passing into the epiphysis on one side, will exert a restraining force on the whole epiphysis; this will be complete at the side of insertion, but less effective on the opposite side.

The arrest of growth by a unilateral wire or staple, when utilized clinically, may correct a growth deformity, but at the same time there is the possibility of arresting total growth in length. One should be careful, also, in the selection of the type of lesion for unilateral growth arrest. If the deformity is due to destruction of the plate on one side from injury or disease, it is easy to see why a unilateral staple will not correct the deformity, because the injured plate has lost its power to proliferate and to push the epiphysis ahead on that side. In fact, a restriction is present on both sides, and a staple would merely prevent further deformity and length growth. Repeated osteotomies to correct the deformity would be advisable.

On the other hand, deformity due to some factor apart from the plate or to some disease which has not completely destroyed the growth power may be corrected by a unilateral growth arrest. The loss of total growth will have to be kept in mind. It is possible in humans, where there is a long growth period, that a compensatory growth increase may take place.

Clinical application and long-time growth observations would be important to decide this point, or experiments on an animal with a longer active growth period than that of the dog, which is not more than nine months.

The question as to whether or not growth is normal after the removal of the wire loop or bilateral staple is difficult to answer. In the first place, additional disturbances to the circulation undoubtedly occur in the removal of the wire or staple, which will have some inhibiting effect on growth. Then there is the possibility of mechanical injury in removing the wire or staple, which becomes more or less imbedded with the lapse of time. If trauma has been sufficient, an osseous bridge may form after the operation, restricting growth. In some of the experiments an increase in the rate of growth undoubtedly occurred after removal of the staple, but it did not reach that of the normal. However, the active growth period of the dog is less than nine months, so that it is difficult to say what would happen in the human being, where the period of growth continues for many years. Experiments on animals with a longer period of growth should be performed to obtain further information on this particular phase of the subject.

In some of the experiments, there was evidence of premature closure of the epiphyseal plate. This usually took place near the time of normal cessation of growth. The findings were not uniform, and further studies are necessary.

In some cases in which staples were inserted on both sides of the epiphyseal plate, there was broadening of the articular end of the bone. There was also a tendency for some of the plates to be rotated and to assume a different location from their original site. It is possible that an irregular or asymmetrical growth disturbance may play a factor in these observations.

It is important to make careful follow-up observations and to take repeated roentgenograms in cases of growth arrest by mechanical means. In humans, this is borne out by the clinical findings in one patient, where a wire loop was inserted around the epiphyseal plate to arrest growth. During a period in which this patient was not followed closely, the wire broke on the lateral aspect, and an overgrowth took place on that side, causing genu varum. This had to be corrected subsequently by an osteotomy, which could have been avoided by repeated roentgenograms during the growth span.

CONCLUSIONS

Wire or staples, applied unilaterally across the epiphyseal cartilaginous plate, will arrest length growth on the side of insertion. There will also be restriction of growth on the opposite side to a lesser degree, but sufficient to cause a loss in length growth of the bone.

It is inadvisable to try to compensate for a growth deformity, due to a destructive injury to the plate on one side, by the insertion of a staple or wire on the opposite side of the plate.

If the deformity was caused by factors outside of the plate, it may be corrected by unilateral wires or staples, but loss in length of the bone may occur.

It is difficult to determine definitely whether or not growth is as active after temporary retardation by a wire or staples. It was not so active as on the normal side, but it is possible that injury to the circulation and trauma to the plate disturbed the growth. There was evidence of a premature closure of the plate in some of the experiments.

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LATERAL VIEW OF THE PELVIS IN EXAMINATION FOR HIP DISLOCATION

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In those institutions where a number of persons are seen who have been injured in industrial, automobile, and farm-machinery accidents, an appreciable number of those hurt are examined roentgenographically for dislocation of the hip. The examination may reveal a simple dislocation of the head of the femur, but the usual finding is a dislocation of this type, combined with a fracture of the rim of the acetabulum.

The common procedure in such cases is to take stereoscopic films of the pelvis and both hips. Due to the fact that such an examination does not always give complete information, whenever possible, we have resorted to an additional roentgenogram, consisting of a direct lateral view of the entire pelvis. The need for additional information, in these cases, was brought to our attention by examination of those patients brought in with a dislocated hip or a fractured pelvis, complicated by pregnancy. The first such patient was not examined by lateral roentgenograms until after the fractures in the pelvis showed some evidence of healing. Measurements had been requested to determine whether or not the pelvic deformity would interfere with a normal delivery. On the lateral roentgenogram of the pelvis, taken for the purpose of measurement, the degree of posterior displacement of the head of the femur was demonstrated more accurately than could be determined from the stereoscopic films.

The technique employed and the position of the patient for such a roentgenogram are the same as used for the lateral view in pelvic-measurement examinations, fractures of the sacrum, and lesions of the lower lumbar spine and lumbosacral disc. Routine roent-

Fig. 1

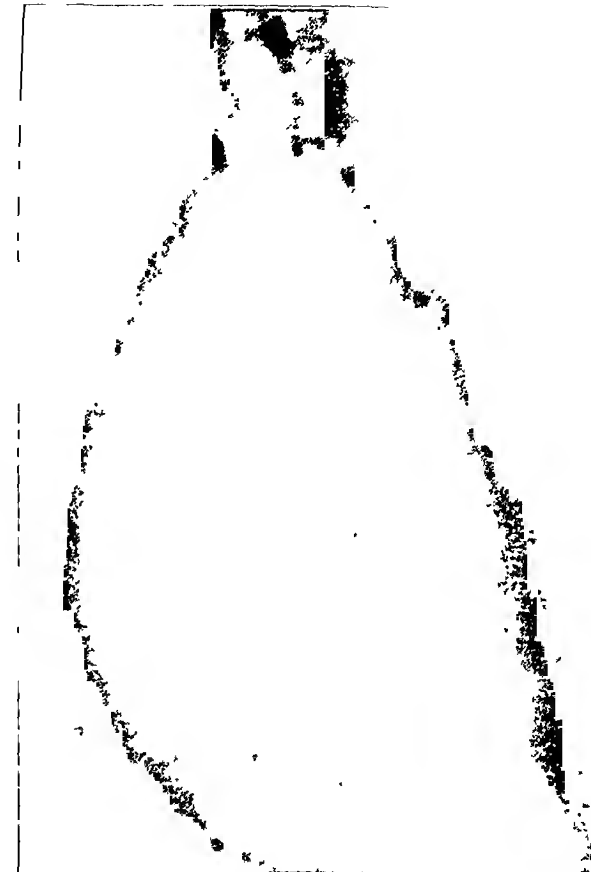

Fig. 2

Fig. 1: Anteroposterior roentgenogram of the pelvis and both hips, showing an acetabular fracture and, in stereoscopic films, a dislocation posteriorly of the head of the femur.

Fig. 2: Lateral view of the same pelvis as seen in Fig. 1, showing the proper position of the patient. The posterior displacement of the head of the femur in relation to the acetabulum is also shown. This degree of displacement cannot be evaluated in the conventional anteroposterior stereoscopic films.

genograms of the pelvis and both hips are made first; and, if they show extensive fractures of the pelvis, then the lateral roentgenogram is omitted for obvious reasons. If the roentgenograms reveal only a dislocation of the femoral head, or a dislocation with an acetabular fracture, the patient is placed in the proper position on the Bucky table for a lateral roentgenogram of the pelvis. Sometimes it is more comfortable for the patient to lie with the injured hip on the table top instead of away from it. The additional roentgenogram not only shows the amount of displacement of the head of the femur, but also shows the position of any small bone fragments, if present, either inside or outside of the joint capsule. Such a roentgenogram is also of value in the check-up examination following manipulation for reduction in a simple dislocation without fracture.

Examinations with a portable machine, while the patient is in bed and in an extension apparatus, have not been satisfactory, either with or without a stationary grid.

SPIKE OSTEOTOMY FOR THE CORRECTION OF VARUS AND ROTARY DEFORMITIES OF THE HIP *

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The present description concerns a simple method of subtrochanteric osteotomy that provides firm postoperative stability in the correction of varus and rotary deformities of the hip. Transverse or oblique osteotomy planes, as generally utilized, are often unstable. Even when the original operation is planned and executed with complete accuracy, it is common for the fragments to slip, so that the final angular correction is less than that planned and the extremity is accordingly shortened.

Of course, compromised results of this sort can be averted by a number of expedients, but each presents certain disadvantages. Internal fixation by instruments of the Blount type make it impossible for the surgeon to adjust the osteotomy angle during the early postoperative period. The operation is prolonged and moderately difficult, and healing is often slow. Pins incorporated in plaster, as used by Schanz, Roger Anderson, and Irwin, have proved risky for routine use, because of the ease with which infection travels along the elements protruding from the skin. The plan of delaying angulation until after some callus has formed adds a routine and unnecessary operative procedure. The curved and the inverted V osteotomies preclude slipping only at a right angle to the plane in which the V or curve is constructed. When the plane of the V is anteroposterior, to prevent medial slipping, an extensive anterior approach is required.

The spike operation offers a simple method of avoiding most of these disadvantages. It is so simple that the procedure must have been utilized before, although no record of its performance has been found in the relevant literature. The objective of the operation is the creation of a spike on the distal fragment for insertion into the trabecular bone of the femoral neck (Fig. 1).

* Read before the Orthopaedic Section, New York Academy of Medicine, May 16, 1947.

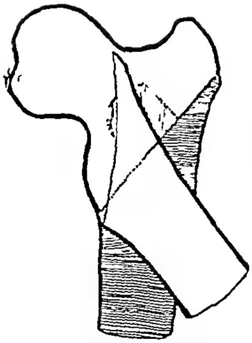

FIG. 1

Fig. 1: Diagram showing the objective of the operation.

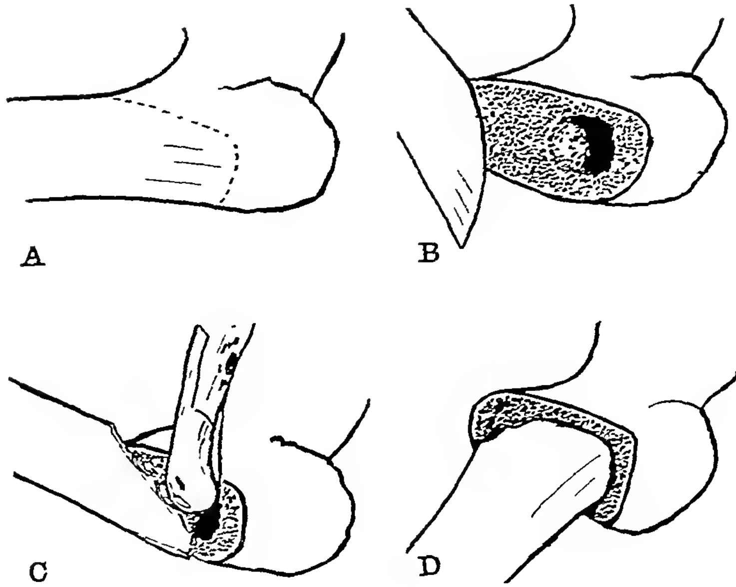

FIG. 2

Fig. 2: The operation.
A: The osteotomy plane.
B: The curetted pocket.
C: Trimming the spike.
D: Abduction and insertion of the spike.

Operative Procedure

Spike osteotomy is accomplished as follows: A lateral approach is employed, with circumferential subperiosteal exposure of the femur for two or three inches below the vastus ridge. The osteotomy plane commences just at the ridge, terminating medially just below the lesser trochanter (Fig. 2,*A*). Some care is necessary to avoid splitting the anterior cortex, and it has been found best to osteotomize this cortex first from its anterior aspect, this line of section being followed later from the side with the broad osteotome.

FIG. 3

D. K., aged five (No. 533131). Congenital coxa vara, left. A single plaster spica was worn for three months after operation, followed by prompt resumption of weight-bearing.

Distraction of the fragments is accomplished by adduction of the leg and by the use of bone hooks. In this position it is an easy matter to shape the distal fragment with the rongeur, and to create a pocket for the insertion of the spike into the trabecular bone of the proximal fragment (Fig. 2,*B*). This pocket may be curetted to follow any desired plane; a depth of one-half to three-quarters of an inch is ample (Fig. 2,*C*). Fitting the spike into the pocket presents no difficulty, but may require approximately one-quarter of an inch of shortening of the spike. Abduction locks the fragments firmly together in the rotary relationship that the surgeon desires, and the almost rectangular spike maintains it there (Fig. 2,*D*). The degree of abduction determines the corrective angle.

Postoperative immobilization is possible by a single or double spica, but, since abduction locks the position firmly, a leg-to-leg plaster only is required. This furnishes all the immobilization necessary for stability, and allows the patient greater postoperative freedom. For greater comfort it has been our practice to apply a single spica after the operation, changing it a week or two later for a leg-to-leg type of plaster.

Advantages

With the spike method, stability is attained at no sacrifice of leg length and even, in some cases, with gain. This stability is attained in a single-stage procedure without the use of foreign fixative material, and it is firm enough so that the single or double spica can be dispensed with. Abduction only is required, and this can be accomplished by a leg-to-leg plaster, from toes to mid-thigh. The operation preserves the ability to adjust the osteotomy angle during the early postoperative period. The broad osteotomy surface provided by the operation expedites bone healing, and blocks the characteristic tendency of osteotomies to "buckle" after the plaster has been removed. Because immobilization of the hip in plaster is unnecessary, the joint moves freely as soon as the leg plasters have been removed, and convalescence is speedy.

Indications

Spike osteotomy has been utilized only for angular and rotary corrections,—not for the therapy of ununited hip fractures. For obvious reasons the procedure cannot be satisfactorily executed when very small corrections are desired, nor can it be used when the hip is ankylosed, except in the presence of severe adduction deformity.

SKELETAL HEMANGIO-ENDOTHELIOMA

A Case Report

BY EMIL D. W. HAUSER, M.D., AND GEORGE A. CONSTANT, M.D., CHICAGO, ILLINOIS

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Skeletal hemangio-endothelioma is a rare condition and one which is not easily recognized early. In order to help establish early diagnosis, and to evaluate the therapeutic measures usually employed, a report is presented of a patient who is still living nine years after the diagnosis of hemangio-endothelioma was confirmed. The case demonstrates some of the complications encountered, as well as indicating the possible prognosis. Since this patient had a single lesion in each hip, the question arose as to whether there were two primary lesions, or whether one was a metastasis. There are cases on record in which metastases have been reported. However, the history and course of the case herein presented led to the opinion that there were two primary lesions.

A white woman, forty years old, came to us, complaining of severe pain and swelling in the right hip. One year before, she had suffered a pathological fracture of the neck of the right femur. Roentgenograms made at another hospital had revealed, in addition to the fracture, a cystic lesion on the neck of the femur. She had been told at that time that she had but a few weeks to live. She lived, however, one year without much change in her symptoms, and it was then that she consulted the senior author. Physical examination showed the right leg to be one inch shorter than the left. The muscles of the right thigh were somewhat atrophic, and there was some swelling in the region of the greater trochanter. The red-cell and the white-cell counts were normal. The sedimentation rate was twenty-three millimeters per hour. Urinalysis revealed nothing unusual. There was no Bence-Jones protein. A roentgenogram (Fig. 1) confirmed the pathological fracture, with non-osseous union. The cystic lesion was also evident, but showed little change from its appearance in the roentgenograms which had been made one year before.

Since there was so little change in the lesion after a year, it was felt that it might not be malignant. The patient was admitted to Passavant Hospital for diagnosis. In case the lesion proved to be benign, immediate excision was to be performed. Roentgenographic studies of the chest and other long bones were made. There was nothing unusual in the chest, but the neck of the left femur showed a cystic lesion very similar to the one in the right hip. The presence of two lesions pointed toward malignancy, and it was believed that perhaps both were metastatic lesions from a primary site that had not yet been recognized. A thorough search for a primary lesion was made, but none was found. A subsequent roentgenogram (Fig. 2) showed an increase in the size of the lesions, and deep x-ray treatment was then advised. The maximum amount of therapy was given, but the lesions continued to grow. Radium needles were then inserted deep into the tumor tissue, but this treatment also failed to halt the disease. Roentgenograms (Figs. 3 and 4), made during this period, showed how the disease had progressed. All of the bones of the pelvis had become involved. Trabeculation and invasion of the surrounding soft parts had become prominent features in the roentgenograms.

FIG. 1

Roentgenogram made February 10, 1938, shows the cystic lesion and also the non-osseous union of the pathological fracture of the neck of the right femur.

The roentgenologist suggested that the lesion resembled that of echinococcus disease. In order to rule out any type of cyst or abscess, aspiration with a spinal-puncture needle was carried out. Serum was all that was obtainable. It was felt that a large trocar with a sharp edge could be used to obtain material for examination. After the trocar had penetrated the tissue, the plunger was withdrawn, and suction was applied. In this way a small amount of tissue was obtained. Laboratory analysis showed that the tumor was made up of small, irregu-

larly shaped cells, but no mitosis was evident. There was not enough tissue to establish definitely the type of tumor; therefore, it was decided to perform a biopsy. An incision was made above the greater trochanter of

FIG. 2

Roentgenogram made July 23, 1938, shows an increase in the size of the lesion of the right femur and the beginning of the cystic formation in the neck of the left femur

FIG. 3

Roentgenogram made November 26, 1938, shows greater destruction of both femora and invasion of the surrounding soft parts. Also note the trabeculation.

the left femur. The tumor was found to be beneath the muscle. The muscle was divided; and, as soon as the tumor was encountered, there was profuse bleeding. The blood gushed forth so that it was necessary to con-

Fig. 4

Roentgenogram made April 18, 1939, shows the rapid progress of the destructive process. Invasion of the bony pelvis has taken place.

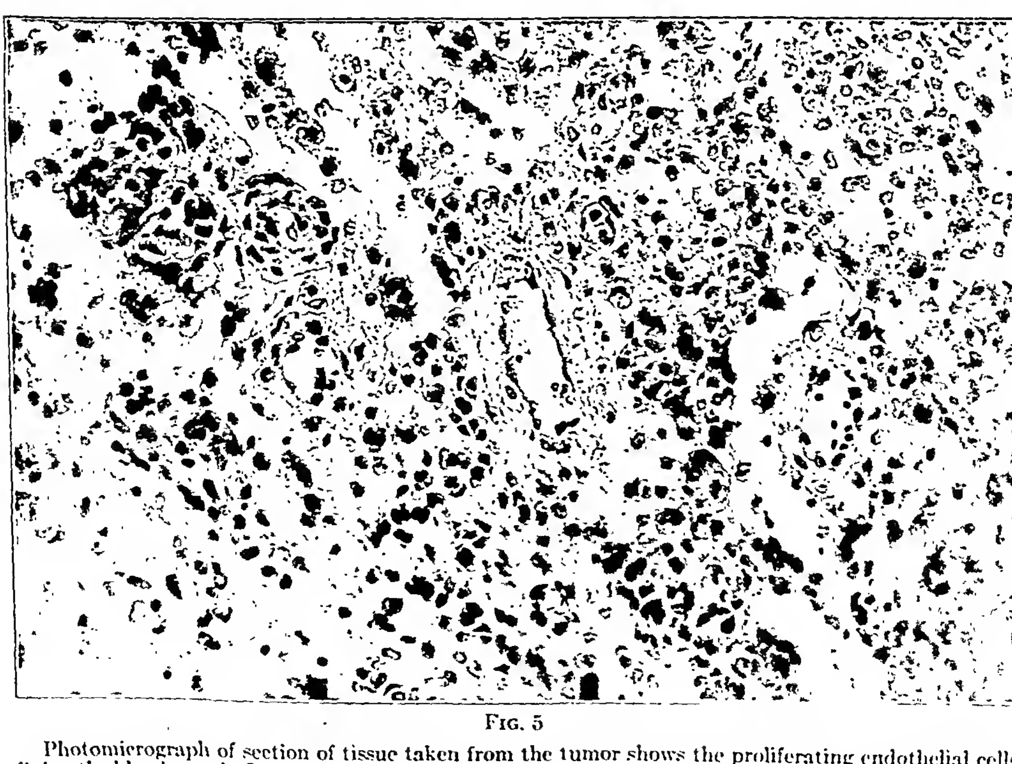

Fig. 5

Photomicrograph of section of tissue taken from the tumor shows the proliferating endothelial cells lining the blood vessels. In many areas the tumor cells have become arranged in whorls with a suggestion of a lumen in their midst.

FIG. 6

Roentgenogram made February 20, 1945, shows how the lesion has invaded almost the entire bony pelvis. (Shaft of the right femur not shown.)

trol the hemorrhage by blocking the opening through the muscle with a gloved hand. Palpation of the tumor, revealed it to be made up of finger-like masses which invaded the bone. The tissue was soft and friable, and had the consistency of an oyster. Portions of these masses were removed with fingers and scissors. The muscle was packed immediately and firmly with a large gauze sponge. Then the muscle was sutured, as the pack was gradually removed.

The tissues were fixed, mounted, and stained with hematoxylin and eosin. Microscopically the sections (Fig. 5) showed a predominance of mature and immature endothelial cells, springing from the endothelial lining of the blood vessels. There were no mitotic cells. The tumor cells, in many areas, were arranged in whorls—cells piled one upon the other—with a suggestion of a lumen in their midst. The sections were similar to those studied by Kolodny. (Although the alveolar arrangement of the cells in Kolodny's cases was much more prominent than in this one, the other aspects were quite similar,—the tendency toward vasoformation, the presence of large cells containing vacuolated or scanty cytoplasm, and the proliferation of the endothelial cells lining the blood vessels.)

The patient recovered from the surgery, and is living today. The tumor has increased in size (Fig. 6), and it has invaded the entire pelvis. In spite of the enormity of the tumor and the pathological fracture, the patient is able to be up in a wheel chair occasionally. The pain has been controlled by various anodynes. Recently the patient has been receiving frequent doses of dilaudid hypodermically. She has survived pneumonia during which her temperature rose to 105 degrees. The fact that this patient has lived nine years without any further lesions seems to indicate that the two lesions are not metastatic. Furthermore, considering the period of time, the size of the tumor, and the amount of involvement, it is remarkable that the patient has lived so long.

DISCUSSION

To make an early diagnosis one must first suspect the existence of a hemangio-endothelioma. Any skeletal lesion which appears by roentgenogram to be (1) cystic, (2) trabeculated, and (3) invading the surrounding soft parts, merits the consideration of skeletal hemangio-endothelioma in the differential diagnosis. In all the cases in the literature which were examined roentgenographically, these three features were the outstanding characteristics of the lesions. This is also true of the case here reported.

The definitive diagnosis, however, rests upon the microscopic examination of a biopsy specimen. A biopsy should be performed on a lesion displaying any of the above features in order to differentiate it from (1) a benign cyst of the bone, (2) metastatic carcinoma, (3) giant-cell tumor, (4) osteosarcoma, (5) chondrosarcoma, (6) echinococcus disease of the bone, and (7) hemangioma. A microscopic examination of a sample of the lesion, which shows a predominance of mature and immature endothelial cells springing from the lining of the blood vessels, is, according to Kolodny, the only confirmation of the diagnosis.

Surgical intervention is the only procedure that at present offers any benefit. Of the twenty-three cases found in the literature, nine were treated surgically. Pritchard's patient was well three months later. In the case reported by Lutz and Pusch, the patient was well six months following surgery, at which time she died of coronary thrombosis. Petit-Dutaillis, Bertrand, and Messimy did not mention the longevity of their patient. They reported, however, that she became well, following excision of a hemangio-endothelioma from the occipital bone. Fienberg and Baehr did not report their postoperative results. Thomas reported a patient who was alive ten years after surgery. This is the longest period of survival following surgery among the reported cases. In another case, however, Thomas said nothing about the post-surgical course. One of the patients reported by Kolodny died four years after an amputation. Although no autopsy was performed, it was thought that death resulted from metastases. Jack and Faunce reported a case of a patient who died nine days postoperatively. The lesion had already metastasized to the brain. Stout reported a case in which metastases had developed three months following curettage of the lesion.

With regard to deep x-ray therapy, the literature and our experience with the case reported in this paper show that this type of therapy does not resolve the lesion. Pritchard, Lutz and Pusch, and Fienberg and Baehr all resorted to deep x-ray therapy before proceeding surgically, and in all of these cases radiation therapy failed to halt the disease. It would seem, therefore, that surgical intervention offers the most hope. We, therefore, recommend early removal of the lesions where this can be done. The value of surgical treatment, however, has not been fully established; this remains for future postoperative studies to determine. Enough is known about the pathology of the disease so that a diagnosis can be made. The emphasis should now be shifted to a study of the therapeutic results gained by surgical intervention.

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A SKULL-TRACTION APPARATUS

BY THEODORE H. VINKE, M.D., CINCINNATI, OHIO

A radically different and efficient type of skull-traction apparatus is designed to lock safely and securely in the skull, thus reducing to a minimum the possibility of its pulling out, once it has been properly inserted. The apparatus has an eccentric blade which fastens into an undercut hole in the outer cortex of the skull. The eccentric blade easily locks and unlocks the apparatus in the bone. To make this possible, the holes in the skull must be accurately placed and drilled. This is done by using a drill of predetermined length, which is placed in the bushings of the apparatus, so that it will drill the holes as perpendicular to the bone as possible, and also directly opposite each other. The use of these bushings provides great accuracy and precision in drilling the holes.

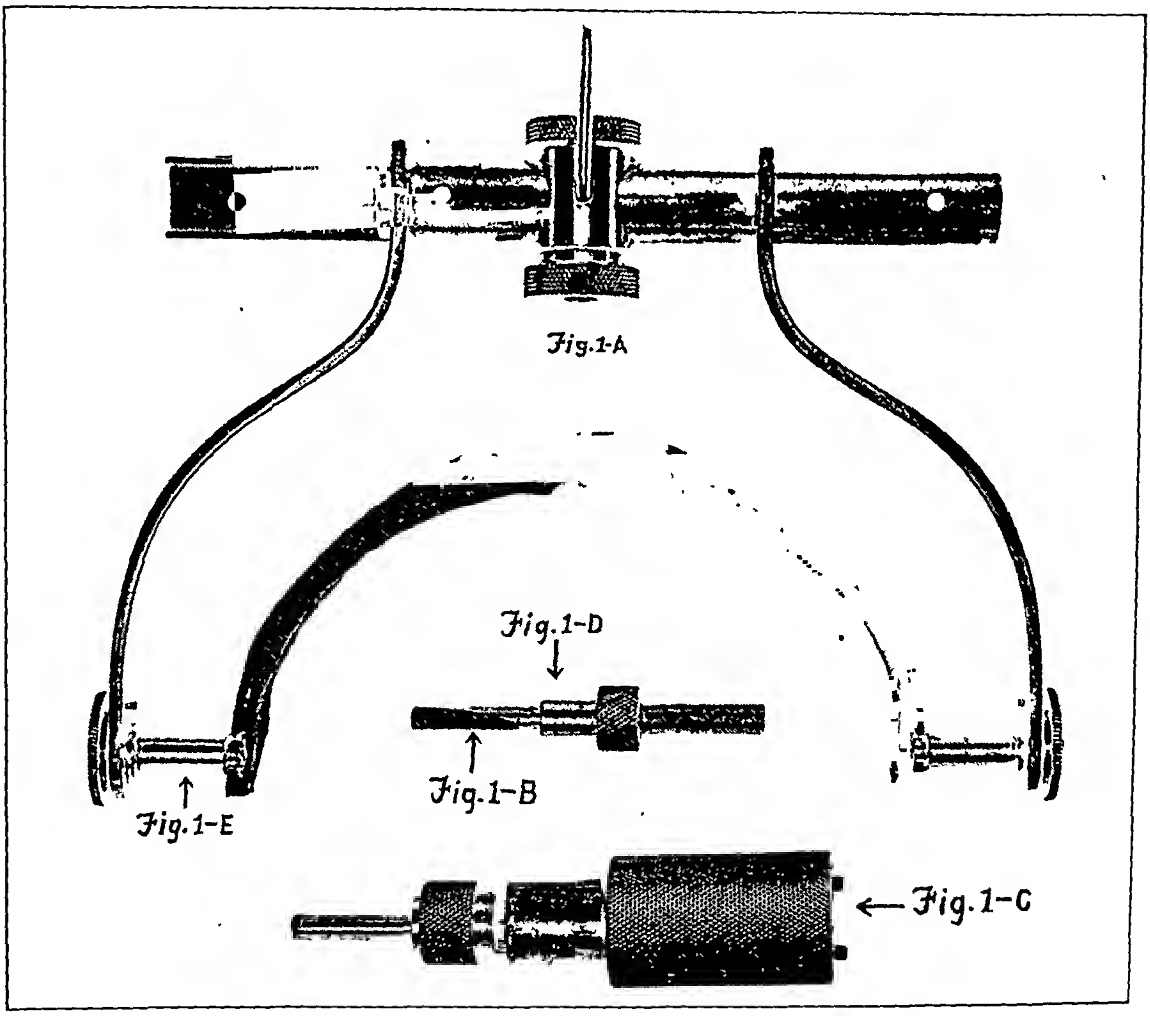

FIG. 1

Entire traction assembly in section of skull. (Drill and undercutting tool are included.)

The skull-traction apparatus and tools consist of three separate parts: first, the drill (Fig. *1-B*), second, the undercutting tool (Fig. 4), and third, the traction device (Fig. *1-A*). The drill (which should be used in a Jacob's chuck) should be of the right diameter to allow it to slide through the bushings on the side arms of the apparatus. A guard on the drill (Fig. *1-D*) is a simple and positive control over the depth to which the hole is drilled. The hole should be deep enough to go through the outer cortex of the parietal region of the skull, and should be placed about one inch above the ears in a relatively flat area of the skull. The bushings (Fig. *1-E*) are permanently attached to the apparatus and are larger

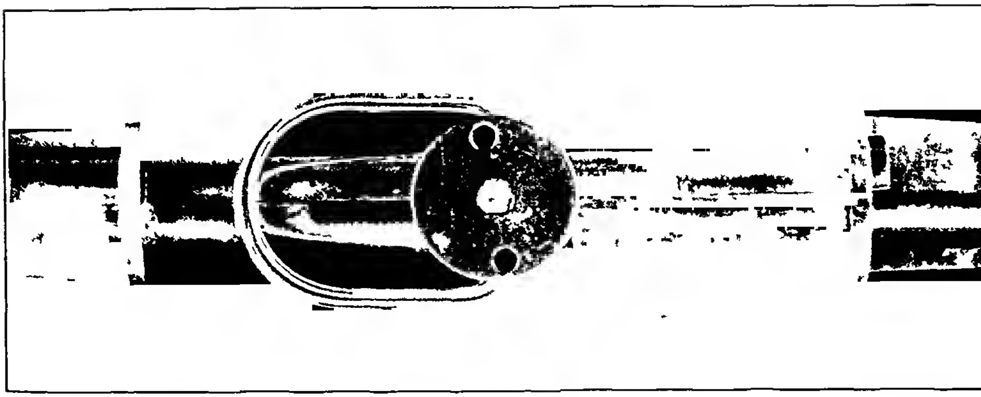

Fig 2
Automatic centralization of traction

than the holes in the bone, which prevents the locking pin from being forced through the skull by pressure or by accidental blows on the side of the frame.

The undercutting tool makes the bottom of the holes in the bone larger in circumference. The tool is so made that it cannot go any deeper than the hole made by the drill. Several successive cuts are made with this tool by a simple adjustment on the handle (Fig. 4). The holes are thoroughly flushed out with normal saline solution or sterile water and are then ready to accept the locking-pin device.

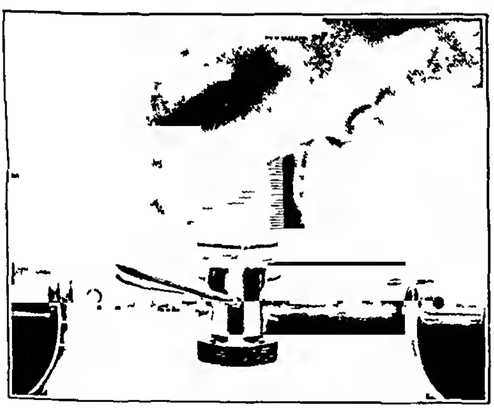

Fig 3
Positive lock of control knob and frame

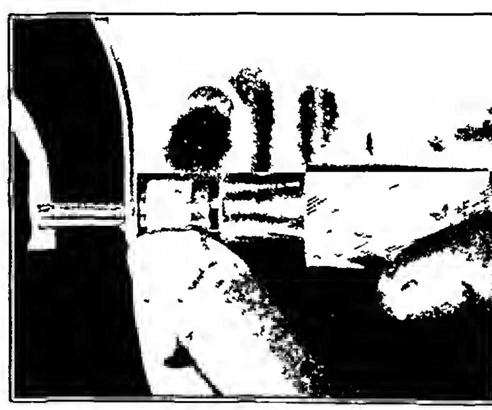

Fig 4
Undercutting tool.

Fig 5
Undercutting hole in skull

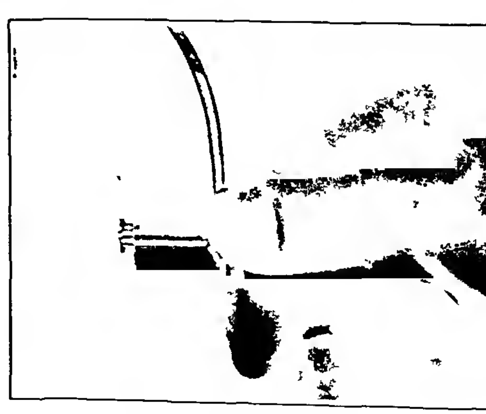

Fig 6
Eccentric blade locked into skull.

The eccentric blade of the traction assembly is locked into position by turning the locking-pin blade 180 degrees. The locking-pin assembly must go in to the full depth of the hole, or until its inner face is in contact with the adjacent side of the frame. The above technique permits drilling the hole, undercutting it, and inserting the traction assembly into one side of the skull before changing the operating position.

The traction frame can be adjusted to the skull with the finger tips by one control knob. This knob automatically fixes the pull of the traction in the center of the apparatus. The frame (Fig. 1) closely conforms to the contour of the skull, in order to permit the patient to turn his head and to lie on either side. The frame is made of stainless, non-corrosive materials and weighs less than eleven ounces. It is rugged enough in construction to suspend the entire weight of the average patient's body.

The release mechanism is simple and effective, and facilitates easy removal of the apparatus from the skull. The entire apparatus can be dismantled for cleaning and sterilization, and re-assembled, without tools.

The procedure can be carried out by any qualified surgeon. It requires five simple manoeuvres, after an incision of three-quarters of an inch (1.8 centimeters) has been made and the bone has been exposed on both sides of the skull. They may be summarized as follows:

1. Place the apparatus in position with the bushings firmly against the skull, and lock it by turning the knob in Figure *1-A*.
2. Drill the hole. If one is worried about going through both cortices, a blunt probe can be placed in the bushing before the entire depth is drilled.
3. Undercut the hole.
4. Flush out the bone chips with water.
5. Insert the locking-pin device and turn it 180 degrees.

The advantages of the attachment are:

Apparatus is safely and positively locked into the skull.

Precision of location and alignment of holes in the skull are possible with bushings.

The use of an undercutting tool permits a deeper and more dependable attachment of the apparatus to the skull.

Traction pressure is distributed over a greater area of bone to prevent the apparatus from tearing out of the skull or damaging the brain.

There is simple and positive control over the predetermined depth of the drilling.

Drill bushings prevent the locking pins from being forced through the skull by pressure or an accidental blow on the side of the frame.

There is automatic centralization of the point of traction.

Adjustment of the traction frame to the skull of the patient can be made by the fingertips with one control knob.

Positive locking of the frame and centralization of the point of traction can be accomplished by one adjustment.

The entire traction apparatus weighs less than eleven ounces.

The shape of the frame conforms closely to the contour of the skull to permit turning of the patient's head and to minimize interference from the apparatus.

Stainless, non-corrosive materials are used throughout the apparatus.

There is a simple and effective release mechanism to facilitate the removal of the unit from the skull, regardless of bone growth.

The improved, time-saving technique permits drilling, undercutting of the hole, and complete attachment of the device to one side of the skull before changing the operating position.

Little special skill or experience is required to safely and positively attach the traction device to the skull.

The operation requires very little of the surgeon's time.

Editorials

The February 1948 number of *The Journal* is the first British issue under the new plan of co-publication. Representative of the orthopaedic surgery of the British nations, most of the clinical and scientific contributions, the proceedings, and the reports are from surgeons of the Commonwealth; there are notable papers from several other countries.

In every respect this number is outstanding. Its articles are being read and acclaimed by surgeons everywhere, who would keep pace with surgical developments,—not only because these contributions are progressive, but for their soundness. Readers of this number find strict adherence to fundamentals.

Among the technical articles, there is a critique of recurrent dislocation of the shoulder in nearly 500 cases, presented in six articles and a symposium; a review of mould arthroplasty of the hip is supplemented by a report of over 250 end results; a fundamental study of plasma-cell tumors is presented by a clinical pathologist and a radiologist; there is an analysis of penicillin therapy for hematogenous osteitis in children; an atlas of osteogenesis imperfecta is the first of an extraordinary series on general skeletal affections; and a number of other notable contributions are included. Every article is significant.

Surgical history and portraits of famous surgeons who have been great in their contributions to orthopaedic surgery have not been neglected.

From the standpoint of publication, this remarkable number is in every sense a work of art. It possesses unmistakably the stamp of the prototype.

To Sir Reginald Watson-Jones, the brilliant and indefatigable British Editor, to the able and hard-working British Editorial Board, and to our fellow orthopaedic surgeons throughout the British Commonwealth, thanks are due for the unusually high standard they have set.

Under the new plan of American-British Commonwealth co-publication, the international scope of *The Journal* has been extended; a fuller realization of aim has become possible. One may readily keep abreast of world progress in orthopaedic surgery today through the single publication. No surgeon can afford not to do so.

The first British issue has been warmly welcomed and is deeply appreciated by all who read *The Journal.*

THE DEVELOPMENT OF PRESENT-DAY KNOWLEDGE OF CONGENITAL DISLOCATION OF THE HIP

In view of what recent decades have contributed to the diagnosis and treatment of congenital dislocation of the hip, one is apt to forget that the roots of our knowledge are traceable to the dim past. After Hippocrates, who was aware of the condition and described it well (De Articulis, Chapter 46), there was a period of silence which lasted almost 2,300 years.

Great tribute should be given to Dupuytren (1826), who was the first to develop a comprehensive picture of the condition in the more modern sense. Pathological evidence, accumulated gradually in connection with therapeutic efforts, may be traced to the beginning of the nineteenth century. Feature after feature was added: the antetorsion of the head (Sandifort), the pathology of the muscles (Hutton), the hourglass constriction of the capsule (Bouvier), the changes of the acetabulum (J. Guérin), and finally the distinction between complete and incomplete dislocation (Parise). In the writings of Lorenz, in 1900 and 1920, we find an integration of all pathological evidence, augmented by his own investigations. It is not too much to say that the masterful monograph of Putti, in 1937, is the classic presentation of present-day knowledge of the pathology of this deformity.

The history of the treatment of congenital dislocation of the hip is more dramatic. Omitting such attempts as Kerkring's, who is credited as being the first to undertake the traction treatment, we may begin with Pravaz (1828), because his principle was gradual reduction by extension; over many byways and after errors, this finally ended up with the reduction manoeuvres of Paci and Lorenz.

It is interesting to note that, in the 1880's, the open operation had its first advocate in Poggi, and that it was further substantiated and improved by Hoffa. Lorenz, quick to recognize the importance of technical advances, elaborated on them, calling it the method of Hoffa-Lorenz. The bloodless reduction itself should be credited to Augustino Paci, whose first report appeared in 1880 and whose method parallels that of Lorenz, except for failure to maintain the proper end position, a point for which full credit is due to Lorenz.

It is a matter of common knowledge that the glowing reports of earlier surgeons on the end results of the bloodless treatment were not borne out by later statistics, and so it is not surprising to see a revival of the open method in 1920, with Galloway of Winnipeg as the foremost advocate. Although only a few surgeons at

this time accept the open method for universal application, we know from reports of Gill, Kidner, Howorth, and many others that it has a definite place and fills a need in cases in which the dislocation is irreducible or irretainable by the closed method.

The greatest advance of later years in treatment is the abduction method, and here the credit goes to Putti for insisting upon early diagnosis and for giving us the technique of the earliest reduction.

Late statistics certainly bear out the great superiority of the abduction treatment, if undertaken in the first year, over the bloodless method, even as it is modified at the present time. After the first year, we believe that the bloodless method of Paci and Lorenz, with Ridlon's modification of technique, still is the method of choice within a restricted age limit. At the same time one must concede to the open method those cases in which reduction cannot be attained or retained, owing to unsurmountable obstacles.

Since we have learned to relinquish the use of excessive force, the reduction trauma has been minimized and, with it, the subsequent degenerative changes of the femoral head.

These later years have produced three definite additions to the general principles of the treatment: first, that the early abduction treatment is the least traumatizing and, therefore, the most promising of all methods; second, that accurate concentric reduction of the head alone makes possible a proper formation of the acetabular roof; and third, that before weight-bearing is permitted, prolonged after-treatment for the development of the abductors and extensors is essential.

The more recent operative procedures of Colonna and those of Leveuf and Zahradníček likewise are based upon the postulates of concentric reduction and avoidance of reduction trauma.

At present, there is sufficient evidence to judge the merits of closed reduction on the basis of long-range observations. We still have to await the last word on the evaluation of open reduction as the method of choice. However, open reduction has established itself as an alternative, within limitations, in cases not responding to closed reduction.

Arthur Steindler, M.D.

CONGENITAL DISLOCATION OF THE HIP

The term "congenital dislocation of the hip", which is deeply rooted in the literature, does not accurately and comprehensively describe this deformity. Dislocation may not be present at birth, but may occur at some postnatal period. Complete luxation may never take place, but the deformity may persist as a subluxation. There has been an abnormal morphogenesis of the hip joint, which may or may not cause dislocation and which may or may not be remedied. The term "congenital dysplasia of the hip" more accurately describes this underlying defect in the growth processes.

The etiology of the condition is still under dispute. The genetic theory maintains that the departure from normal growth is due to some defect in the particular genes which are responsible for the development of the hip joint. The mechanical theory attributes the pathological changes to the operation of adverse mechanical forces during the period of growth *in utero*. Another suggestion is that constitutional conditions of the mother, during the period of pregnancy, may influence the growth processes in the foetus. Embryological studies have not as yet determined the etiological factors in congenital dysplasia of the hip. It may be possible that it is not necessary to attribute all cases to a single factor, inasmuch as there are so many variations in the form and the degree of the dysplasia and in the possibility of recovery.

Much advance has been made during recent years in knowledge of the pathology. The older descriptions, which are those usually found in textbooks, were made from the dissecting table and dealt largely with the secondary pathological anatomy of dislocation,—that is, with the changes which occur in the structures of the hip after dislocation. Knowledge of the primary changes which make dislocation possible or inevitable has been gained in the operating room. This has brought a much clearer understanding of the nature and of the elements of congenital dysplasia of the hip, and has guided us to better methods of treatment. The explanation of the primary pathological anatomy must be found in the etiological factors which produce the divergence from normal morphogenesis.

The prognosis depends upon the form and the degree of pathological divergence from the normal, and upon the ability of the structures of the hip to resume or to continue their growth toward the normal under favorable circumstances. Because there is a great diversity of anatomical deformity, it is illogical to expect uniform results from treatment. The most severe deformities have their origin in embryological or early foetal life, and are often accompanied by deformities of other parts of the body. They are incurable. The only available treatment may be a palliative operation at some appropriate time, to reduce the disability. Fortunately, these cases constitute a very small proportion of the total number of cases of dysplasia of the hip or even of the frank dislocations. If the deformities arise in later foetal life and, therefore, are not genetic in their origin, they are less severe and the prognosis for the development of a normal hip is favorable. This type is best represented by the so-called predislocations. Some of these probably recover spontaneously; many of them recover rapidly after birth as a result of a minimal term of treatment by abduction; but, at

best, in only a few of these cases do perfect hips develop, and only after prolonged treatment. There is some etiological factor or some growth factor that is obscure.

Insufficient study of the predislocations has been made in this country, largely because this condition is not diagnosed frequently enough at, or shortly after, birth. An accurate prognosis of postnatal dislocations cannot be made in any particular case at the time either open or closed reduction is accomplished. Insufficient accurate end-results studies have been made, either of open or closed reductions, to determine definitely the proportion of cases that are curable. Present indications are that it is not greater than one-fourth to one-third, if we accept as the criterion of cure the development of perfect or normal anatomical structures of the hip joint. There may be a prolonged period of normal function in many cases where anatomical perfection is wanting, but the continued mechanical wear and tear in an abnormal joint is almost certain to cause, sooner or later, the symptoms of traumatic arthritis. Many instances of this condition have been observed.

Our ideas concerning the treatment of congenital dislocation have changed greatly during the past fifty years. The recognition of predislocation in the newborn and of the dysplasias without dislocation that may be present at any age, the appreciation of the necessity of prolonged observation after reduction, the improvement of surgical technique and the origination of new surgical procedures, a better understanding of the primary and of the secondary pathological anatomy, and a clearer distinction between perfection and the varying degrees of imperfection of the end results have increased the extent and the precision of our knowledge, so that we are more able than formerly to determine what method of treatment should be employed at any time during the life history of a dysplasia or a dislocation.

In former years the orthopaedic surgeon saw and treated only the hips that were already dislocated. The dysplasias without dislocation were not recognized until after luxation had occurred. Now we know that early diagnosis and adequate treatment can prevent dislocation, although it should be realized that in not all cases do perfect hips result.

Various methods of bloodless reduction were employed, some of them forceful. In time it was recognized that severe force should not be employed to replace the femoral head within the acetabulum.

In many hips in which the surgeon considered the reduction to be successful at the end of one or two or three years, redislocation occurred at some subsequent time. Our present methods of careful and prolonged follow-up and our increased surgical knowledge and skill should prevent redislocations, and thereby greatly reduce the number of old irreducible dislocations that were formerly so prevalent.

The end results of bloodless reduction were so bad that some surgeons advocated the open reduction of all dislocations of the hip. No adequate statistics have ever been presented to prove that a higher percentage of perfect end results may be secured by open than by closed reduction. These surgeons thought that replacement of the femoral head within the acetabulum was all that was necessary to effect a cure. With our better knowledge of growth processes and of the pathological anatomy, we know that this is not necessarily true.

The old irreducible dislocation was formerly considered to be hopeless. It was later discovered that, by various types of osteotomies and by plastic bone surgery, much could be done to relieve these patients of their symptoms and to reduce their disability.

Still later, surgical procedures were devised to reduce those dislocations which could not be done bloodlessly, to stabilize the hips, and to construct a competent acetabulum for those which, after reduction, give evidence of a prolonged or irremediable dysplasia of the acetabular roof which permits subluxation. Whether or not the construction of an adequate acetabulum will lead to the formation of a perfect hip must depend, in large measure, upon the anatomy of the head and the neck of the femur, for not infrequently these structures and the capsular attachment to the neck are abnormal.

In the light of our present knowledge, we may state that most cases of congenital dysplasia of the hip without luxation are curable; that, of the more severe dysplasias which are marked by dislocation, only about one-third are curable; and that the nature of the deformities of bone and soft structures of the hip which are present when treatment is instituted determine in great measure the ultimate end result. If the surgeon is not always able to secure a perfect anatomical end result, he may do much to secure useful function.

A. Bruce Gill, M.D.

CORRECTION

An error was made in the paper by Dr. John Marquis Converse, "Plastic Repair of the Extremities by Non-Tubulated Pedicle Skin Flaps," which was published in the January 1948 issue of *The Journal*. On page 169, the first two lines of the second paragraph should read: "A widely known delayed flap is Gillies's tubed pedicle flap. The *disadvantage* of the tubed flap is the relatively long time required for its construction and transfer (Table I)."

BENJAMIN P. FARRELL

1870–1947

Dr. Benjamin P. Farrell, Professor Emeritus of Orthopaedic Surgery, died on December 27, 1947, after a protracted illness. Dr. Farrell was born at Pittsfield, Massachusetts, on May 22, 1870. He received his medical degree from the Long Island College Medical School, in 1904. Following this, he was an intern at the Newark City Hospital from 1904 to 1906. In 1906 he received an appointment at the New York Orthopaedic Hospital, to which institution he devoted his entire career until his retirement in 1940. Dr. Farrell was associated with Russell A. Hibbs and was his valued assistant during the period when Dr. Hibbs made so many contributions to orthopaedic surgery, including the operative treatment of joint tuberculosis and the development of the spine-fusion operation.

Dr. Farrell became Surgeon-in-Chief of the New York Orthopaedic Hospital in 1932, after the death of Dr. Hibbs. In 1918, the same year in which Dr. Hibbs became Professor of Orthopaedic Surgery, Dr. Farrell was appointed Assistant Professor. He later became Associate Professor, and then Professor and head of the department. He was Consulting Orthopaedic Surgeon to the French and Englewood Hospitals, and had a large private practice in New York City.

Dr. Farrell was a Fellow of the American College of Surgeons and The American Academy of Orthopaedic Surgeons, and a member of The American Orthopaedic Association, of which he was at one time Vice President.

In 1907, Dr. Farrell married Frances Lillian Mitchell, who died in 1942. They had no children.

He had a great capacity for making enduring friendships, and endeared himself to all of his associates and his many friends.

J. ARCHER O'REILLY

1879–1947

Dr. J. Archer O'Reilly of St. Louis, Missouri, a member of The American Orthopaedic Association, died in St. Louis on December 5, 1947.

In his death we have lost a great humanitarian, who devoted his life and interest to the handicapped. Born with a congenital defect, he ignored his own handicap so completely that neither his patients nor his acquaintances and friends thought of him as crippled. Dr. O'Reilly's creed was to help the crippled child and the crippled adult to get to the place where they could forget they were crippled.

He often stated: "The crippled child is the raw material from which a valuable citizen can be made. There is no shame in being handicapped; the only shame is in having a child needlessly deformed through neglect."

He was the son of the late Dr. Thomas W. O'Reilly, who practised for many years in St. Louis, and of Mary Archer O'Reilly. He received his A.B. from Harvard University in 1902 and his M.D. from Harvard Medical School in 1906. He served his internship at the Carney Hospital and returned to St. Louis to practise orthopaedic surgery. He became Professor of Orthopaedic Surgery at St. Louis University Medical School, Chief of the Orthopaedic Staff of the St. Mary's group of hospitals, and Associate Professor of Clinical Orthopaedic Surgery at Washington University Medical School, St. Louis. During World War I he was in charge of the Orthopaedic Staffs of Barnes Hospital and Children's Hospital in St. Louis. During World War II he was orthopaedic advisor to the draft boards. He was largely responsible for the organization and development of the Missouri and St. Louis Societies for Crippled Children. He had been President of the St. Louis Society since its founding, and served as President of the State group from 1930 to 1946, when he became chairman of the board; in October 1947, his son, J. Archer O'Reilly, Jr., became President. He had been a member of the Board of Trustees for the National Society for Crippled Children and Adults, Inc., since 1930, and was cited by this group in 1944 for distinguished service to the handicapped. He was a member of the advisory committee of the State Division of Rehabilitation, Department of Public Schools; a member of the board of the Occupational Therapy Workshop and of the St. Louis School for Occupational Therapy; and a member of the Board of Regents, State Cancer Hospital, Columbia, Missouri. From 1930 to 1935 he headed a Red Cross Committee on Vocational Rehabilitation.

At the time of his death he was Professor of Orthopaedic Surgery and Director of the Department at St. Louis University School of Medicine. He was orthopaedic surgeon to the De Paul Hospital in St. Louis and orthopaedic consultant to the Ranken-Jordan Convalescent Home for Crippled Children, St. Louis County.

He was a fellow of the American College of Surgeons, a diplomate of the American Board of Orthopaedic Surgery, a fellow of The American Academy of Orthopaedic Surgeons, and a member of the American Medical Association. He was a member of the St. Louis and Missouri Medical Associations, of the Southern Medical Association, and of the American Rheumatism Association, and a member of the House of Delegates of the American Medical Association. He was a former member of the Board of Governors of the American College of Surgeons. He was chairman of the Committee on Admissions of The American Orthopaedic Association for the year 1934–1935. He was a former chairman of the Orthopaedic Section of the American Medical Association.

Dr. O'Reilly is known for his work on behalf of the handicapped, and an interest which has spanned forty years of medical practice and earned for him national recognition as a friend of crippled children. He was a prolific writer for medical journals. He has consistently stressed the need of total rehabilitation for the handicapped,—education, emotional adjustment, and vocational training, as well as medicine and surgery.

As early as 1917 he was writing about poliomyelitis. In the early 1930's he began advocating private and public aid to victims of cerebral palsy, which he termed "the most neglected handicap"; 1946 saw the beginning of a national effort in this field, and in Missouri a state-wide program was started by the Missouri Society for Crippled Children. Throughout his career, he worked for better laws in Missouri to aid the handicapped, for greater state responsibility for the total rehabilitation of the handicapped, and for revision of insurance laws to encourage employers to hire handicapped persons.

Dr. O'Reilly was married in 1906, in Kingston, Massachusetts, to Jane Elliott Sever. Mrs. O'Reilly, three sons, and four grandchildren survive him. The sons are J. Archer O'Reilly, Jr., of St. Louis; Noel Sever O'Reilly of Toledo, Ohio; and Dr. Daniel Elliott O'Reilly of St. Louis, who plans to follow in the practice of orthopaedic surgery.

On March 27, 1947, the twentieth anniversary of the Missouri and St. Louis Societies for Crippled Children was marked by a testimonial dinner for Dr. O'Reilly. The Societies' tribute stated, in part:

"He has given his life to the promotion of better aid to crippled children throughout the land. He has never denied the plea of a parent or friend of a crippled child when his skill as a surgeon, or his humanitarian wisdom, could be of aid in any way. The crippled children of Missouri owe him a debt that our highest devotion to their welfare will scarcely repay."

LETTER TO THE EDITOR

In the October 1946 issue, an article appeared [Vol. 28, pp. 869-872] by Finch and Roberts, concerning two cases of epiphyseal coxa valga. This greatly interested me, but I am also very much puzzled in trying to harmonize the diagnosis of the position of the femoral head with the physical findings.

In Case 1, it was stated that the patient walked with an external-rotation deformity. Then, after manipulation and cast, she had an internal-rotation deformity of the left lower extremity of 10 degrees, but she still had 15 degrees of external rotation of the right lower extremity. It is evident from the roentgenograms that the head is displaced upward and laterally, but it is difficult to see how the epiphysis can be displaced anteriorly for the following reasons:

1. If the epiphysis was displaced anteriorly, an external-rotation deformity of the extremity would not be expected; however, we do get an external-rotation deformity (sometimes almost as much as 90 degrees) in the ordinary case of coxa vara where the epiphysis is displaced posteriorly.

2. Observation of the lesser trochanter shows that the femur is actually externally rotated, which could hardly be true if the epiphysis was displaced anteriorly.

3. It would be impossible from a study of flat roentgenograms of the head and neck alone, without lateral or stereoscopic roentgenograms, to tell whether the displacement was anterior or posterior. Seventy-five per cent. of the physicians fail to realize the limitations of flat roentgenograms and will conclude, when showed a flat roentgenogram of a fractured tibia, that the fragment casting the denser shadow is actually nearer to them.

Would not a more probable conclusion be that, in these two cases of coxa valga with slipped femoral epiphysis, the slipping occurred posteriorly, as usual, and not anteriorly, as suggested in the article?

T. Gordon Reynolds, M.D.
Glendale, California

News Notes

THE AMERICAN ORTHOPAEDIC ASSOCIATION

The Sixty-first Annual Meeting of The American Orthopaedic Association will be held at the Chateau Frontenac, Quebec City, on June 3, 4, 5, and 6, 1948. This is to be a combined meeting of the British, Canadian, and American Orthopaedic Associations. The tentative program, as submitted by the Program Committee, is as follows:

THURSDAY, JUNE 3

Morning Session

Aseptic Necrosis of Bone Following Trauma.
Edward L. Compere, M.D., Chicago, Illinois (A.O.A.).
Further Comments on Aseptic Necrosis of the Femoral Head, Sequel to Intracapsular Fractures.
W. W. Plummer, M.D., Buffalo, New York (A.O.A.).
Surgical Management of the Aseptic Necrotic Head of the Femur.
D. B. Phemister, M.D., Chicago, Illinois (A.O.A.).
Fractures of the Neck of the Femur Treated by Smith-Petersen Pin Plus Fibula Graft.
J. Patrick, F.R.C.S., Glasgow, Scotland (B.O.A.).
Subtrochanteric Limb Shortening.
Lawson Thornton, M.D., Atlanta, Georgia (A.O.A.).

Noon: First Executive Sessions of the American, British, and Canadian Orthopaedic Associations.

Afternoon Session

Arthrodesis of the Hip—Ischio-Femoral Method.
H. A. Brittain, F.R.C.S., Norwich, England (B.O.A.).
Osteoid Osteoma: A Clinical Pathological Study of a Series of Cases.
Malcolm Dockerty, M.D., Rochester, Minnesota (by invitation);
Ralph K. Ghormley, M.D., Rochester, Minnesota (A.O.A.).
Slipping of the Upper Femoral Epiphysis.
Beckett Howorth, M.D., New York, N. Y. (A.O.A.).
The Management of Incipient Epiphysiolysis of the Hip.
S. Kleinberg, M.D., New York, N. Y. (A.O.A.).
Roentgenographic Changes in Nailed Slipped Capital Femoral Epiphysis.
Armin Klein, M.D., Boston, Massachusetts (A.O.A.).
Subject to be announced.
Sten Friberg, M.D., Stockholm, Sweden (by invitation).

FRIDAY, JUNE 4

Morning Session

Osteo-Arthritis of the Hip Joint: Review of Over One Hundred Cases Treated by Arthroplasty.
Alexander Gibson, M.D., F.R.C.S., Winnipeg, Canada (A.O.A.).
Excision of the Femoral Head and Neck and Angled Osteotomy of the Femur in Ankylosis and Arthritis of the Hip.
J. S. Batchelor, F.R.C.S., London, England (B.O.A.).
A Follow-up Study of Results in Fascial Arthroplasties of the Knee.
J. S. Speed, M.D., Memphis, Tennessee (A.O.A.);
Philip C. Trout, M.D., Roanoke, Virginia (by invitation).
Arthroplasty of the Knee Joint—End Results.
J. Edward Samson, M.D., Montreal, Canada (C.O.A.).
Changes Observed in the Elastic Adipose Tissues with Advancing Years: Results of a Five-Year Study in the Harvard Medical School.
J. G. Kuhns, M.D., Boston, Massachusetts (A.O.A.).
End Results of Physiological Blocking of Flail Joints.
Alberto Inclán, M.D., Havana, Cuba (A.O.A.).

Afternoon Session

Fracture-Dislocation of the Pelvis.
F. W. Holdsworth, F.R.C.S., Sheffield, England (B.O.A.).
Developmental Coxa Vara.
A. B. LeMesurier, M.D., Toronto, Canada (A.O.A.).

Treatment of Some Irreducible Congenital Dislocations of the Hip.
Juan Farill, M.D., Mexico (A.O.A.).
Arthrography of the Hip.
F. C. Durbin, F.R.C.S., Exeter, England (B.O.A.).
Arthrodesis of the Ankle Joint.
W. E. Gallie, M.D., F.R.C.S., Toronto, Canada (A.O.A.).
Estrogens and Bone Formation in the Human Female.
Mary S. Sherman, M.D., Chicago, Illinois (by invitation);
C. Howard Hatcher, M.D., Chicago, Illinois (A.O.A.).
Subject to be announced.
Fuller Albright, M.D., Boston, Massachusetts (by invitation).

SATURDAY, JUNE 5

Morning Session

Congenital Discoid Meniscus.
I. S. Smillie, O.B.E., F.R.C.S., Edinburgh, Scotland (B.O.A.).
Results of Meniscectomy and the Theoretical Aspects of Operative Technique.
J. Charnley, F.R.C.S., Manchester, England (B.O.A.).
Knee-Joint Changes after Meniscectomy.
T. J. Fairbank, F.R.C.S., Reading, England (B.O.A.).
Treatment of Cervical Fracture and Fracture-Dislocation.
Wm. A. Rogers, M.D., Boston, Massachusetts (A.O.A.).
Treatment of Fracture-Dislocations of the Cervical Vertebrae by Skeletal Traction and Fusion—Results Ten Years Later.
W. G. Turner, M.D., Montreal, Canada (A.O.A.);
Wm. Cone, M.D., Montreal, Canada (by invitation).
Organization of an Accident Service.
W. Gissane, F.R.C.S., Birmingham, England (B.O.A.).
Presidential Address.
R. I. Harris, M.B., Toronto, Canada (A.O.A.).

Afternoon Session

Round-Table Discussion on Undergraduate Teaching in Orthopaedic Surgery.
Conducted by A. Bruce Gill, M.D., Philadelphia, Pennsylvania (A.O.A.).

SUNDAY, JUNE 6

Morning Session

Operative Approaches to the Shoulder Joint.
LeRoy C. Abbott, M.D., San Francisco, California (A.O.A.).
External Skeletal Fixation in Orthopaedic Surgery.
J. R. Naden, M.D., Vancouver, Canada (A.O.A.).
The Use of External Pin Fixation in Late Compound Fractures Due to War Wounds.
E. C. Janes, M.D., Hamilton, Canada (C.O.A.).
Treatment of Fractures of the Shaft of the Femur.
Edward Harlan Wilson, M.D., Columbus, Ohio (A.O.A.).
Denervation of the Elbow Joint for Relief of Pain—Preliminary Report.
James E. Bateman, M.D., Toronto, Canada (C.O.A.).
Case Report of Pedicled Nerve Graft with Discussion on the Applicability of Procedure.
F. G. St. Clair Strange, F.R.C.S., Folkestone, England (B.O.A.).
Elephantiasis Associated with Congenital Bands in Children.
A. W. Farmer, M.D., Toronto, Canada (A.O.A.).
Scoliosis Complicated with Paraplegia.
K. G. McKenzie, M.D., Toronto, Canada (by invitation);
F. P. Dewar, M.D., Toronto, Canada (C.O.A.).

The National Foundation for Infantile Paralysis will sponsor the First International Poliomyelitis Conference, to be held at the Waldorf-Astoria Hotel, New York, July 12 to 17.

The program will include scientific and technical papers on research and treatment of poliomyelitis, to be presented by professional authorities in the field from this country and abroad. In addition, there will be panel discussions on the various subjects.

The **Sociedad Española de Cirugía Ortopédica y Traumatología** has recently been organized with the following officers:

President: Dr. M. Salaverri, Bilbao;
Vice-President: Dr. R. San Ricart, Barcelona;
Secretary: Dr. M. Clavel, Murcia;
Vice-Secretary: Dr. C. González, Madrid;
Treasurer: Dr. A. Garaizábal, Madrid.

The official publication of this organization is *Cirugía del Aparato Locomotor* of which Dr. V. Sanchís Olmos is Editor.

The next meeting of this association will be held in Madrid in May. The principal subjects for discussion will be intramedullary nailing in fractures of the long bones and the treatment of scoliosis.

The Sixth International Assembly of the **International College of Surgeons** will be held in Rome, Italy, at the invitation of the Italian Government, during the week of May 16 to 23, 1948, under the presidency of Professors Raffaele Bastianelli and Raffaele Paolucci of Rome, and Mario Dogliotti of Turin. The Secretary of the Assembly is Prof. Giuseppe Bendandi of Rome. Attendance is not limited to the membership of the College; all surgeons in good standing in their medical organizations are invited. Scientific meetings, scientific and commercial exhibits, and visits to the Universities of Turin and Milan have been arranged, together with tours to other medical centers in Europe. A special exhibit of ancient texts on surgery is being arranged by Prof. Davide Giordano of Venice, Honorary President, under the active presidency of Prof. Adalberto Pazzini, Professor of History at the University of Rome. This extraordinary exhibit, dealing with ancient surgery, will be on display in the Vallicelliana Library in one of the historical buildings of the Vatican. Detailed information may be obtained from Dr. Max Thorek, General Secretary, 850 Irving Park Road, Chicago 13.

The Fourth Congress of **The International Society of Orthopaedic Surgery and Traumatology** will be held in Amsterdam on September 13 to 18, 1948. Headquarters for the Congress will be at the American Hotel.

The program has been arranged by Dr. Jean Delchef, Secretary General, and the two principal subjects for discussion will be:

1. The treatment of deforming arthritides of the hip. (Led by Professors Mathieu and Padovani, Paris.)
2. Occult traumatisms of the vertebral column. (Led by Mr. E. A. Nicoll, Manchester, England.)

These topics will also be discussed by other distinguished orthopaedic surgeons including Professors Zahradníček (Czechoslovakia), La Chapelle (The Netherlands), Delchef (Belgium), Wiberg (Sweden), Böhler (Austria), Pais (Italy), Inclán (Cuba), San Ricart (Spain), and Smith-Petersen (U.S.A.). Papers and motion pictures on other subjects will also be presented. Anyone who wishes to present a paper or motion picture should submit the title and a short summary to Dr. Delchef before June 30, 1948.

Arrangements have been made for about 500 rooms for the members and guests of the Society during the time of the Congress. Due to congestion in the city, reservations should be made early and should be sent directly to Dr. J. D. Mulder, Vondelstraat 75, Amsterdam, Holland.

THE AMERICAN ACADEMY OF ORTHOPAEDIC SURGEONS

The Fifteenth Annual Convention of The American Academy of Orthopaedic Surgeons was held at the Palmer House, Chicago, January 24, 25, 26, 27, 28 and 29, 1948, under the presidency of Dr. Rex L. Diveley. The Convention was the largest in the history of The Academy. The Audio-Visual Program, under the chairmanship of Dr. Charles N. Pease, was well arranged and attracted large audiences. The Instructional Courses, under the chairmanship of Dr. Walter P. Blount, provided a wide choice and were well attended. The Scientific Program was arranged by the Program Committee, of which Dr. T. Campbell Thompson was Chairman. This was presented on the afternoon of Monday, January 26, at the morning and afternoon sessions of Tuesday and Wednesday, and at the morning session on Thursday, January 29, as follows:

Monday, January 26

Afternoon Session

Occurrence and Management of Reflex Sympathetic Dystrophy—Causalgia of the Extremities.
James W. Toumey, M.D., Boston, Massachusetts.
Discussion: Harold R. Bohlman, M.D., Baltimore, Maryland.

The Use of Iliac-Bone Grafts in Orthopaedic Surgery.
I. S. McReynolds, M.D., Houston, Texas.
Discussion: Leonard F. Bush, M.D., Danville, Pennsylvania (by invitation).
Fractures of the Carpal Scaphoid.
H. Osmond Clarke, F.R.C.S., London, England (by invitation).
Delayed Bone Graft in the Treatment of Congenital Pseudarthrosis.
John R. Moore, M.D., Philadelphia, Pennsylvania.
Discussion: William T. Green, M.D., Boston, Massachusetts;
Dallas B. Phemister, M.D., Chicago, Illinois.
Short First Metatarsal—Its Incidence and Clinical Significance.
T. Beath, M.D. (by invitation), and R. I. Harris, M.B., Toronto, Canada.
Discussion: Robert Bingham, M.D., Riverside, California (by invitation);
R. Plato Schwartz, M.D., Rochester, New York.

TUESDAY, JANUARY 27

Morning Session
Legg-Perthes Disease—A Method of Conservative Treatment.
Maurice M. Pike, M.D., Hartford, Connecticut.
Discussion: M. Beckett Howorth, M.D., New York, N. Y.;
A. Bruce Gill, M.D., Philadelphia, Pennsylvania.
The Relationship between Congenital Subluxation and Congenital Dislocation of the Hip.
Vernon L. Hart, M.D., Minneapolis, Minnesota.
Discussion: Paul C. Colonna, M.D., Philadelphia, Pennsylvania;
H. Relton McCarroll, M.D., St. Louis, Missouri.
Treatment of the "True" Congenital Luxation of the Hip. Results of the Open Reduction.
Professor Jacques Leveuf, Paris, France.
Aspects of Physical Reconditioning.
Marcus J. Stewart, M.D., Memphis, Tennessee (by invitation).
Vocational Rehabilitation.
Michael J. Shortley, Washington, D. C. (by invitation).
Rehabilitation of the Severely Handicapped.
Henry H. Kessler, M.D., Newark, New Jersey.
Discussion: A. R. Shands, M. D. Wilmington, Delaware;
Rufus H. Alldredge, M.D., New Orleans, Louisiana;
Frank Stinchfield, M.D., New York, N.Y., *Chairman.*

fternoon Session
Dupuytren's Contracture: A Report of Fourteen Cases of Combined Palmar and Plantar Lesions.
J. Vernon Luck, M.D., Los Angeles, California.
Discussion: Arthur Steindler, M.D., Iowa City, Iowa;
H. W. Meyerding, M.D., Rochester, Minnesota.
Criteria for Spine Fusion Following Removal of Protruded Nucleus Pulposus.
Guy A. Caldwell, M.D., and William B. Sheppard, M.D., New Orleans, Louisiana.
Vascular Complication of Disc Surgery.
Edward C. Holscher, M.D., St. Louis, Missouri (by invitation).
Discussion: Raymond E. Lenhard, M.D., Baltimore, Maryland;
James W. Shumate, M.D., San Francisco, California;
Joseph S. Barr, M.D., Boston, Massachusetts;
William B. Sheppard, M.D., New Orleans, Louisiana.
The Problem of the Primary Curve in Idiopathic Scoliosis.
John R. Cobb, M.D., New York, N. Y.
Changing Concepts in Scoliosis.
W. H. Von Lackum, M.D., New York, N. Y.
Discussion: Albert B. Ferguson, M.D., Brookline, Massachusetts (by invitation);
Albert C. Schmidt, Milwaukee, Wisconsin;
Henry F. Ullrich, M.D., Baltimore, Maryland.

WEDNESDAY, JANUARY 28

Morning Session
The Use of Skeletal Traction in the Treatment of Fractures of the Femur.
Edward M. Winant, M.D., New York, N. Y.

Open Reduction and Internal Fixation of Long-Bone Fractures.
Harrison L. McLaughlin, M.D., New York, N. Y.
External Skeletal Fixation in the Treatment of Tibial Fractures.
John R. Naden, M.D., Vancouver, British Columbia.
Discussion: William Darrach, M.D., New York, N. Y. (by invitation);
H. Osmond Clarke, F.R.C.S., London, England (by invitation);
H. Earle Conwell, M.D., Birmingham, Alabama;
Mather Cleveland, M.D., New York, N. Y., *Chairman.*
Surgical Treatment of Non-Union of Long Bones.
Dr. Robert Merle D'Aubigne, Paris, France.
Presidential Address.
Rex L. Diveley, M.D., Kansas City, Missouri.

Afternoon Session
The Cervical Syndrome as a Causative Factor in Certain Shoulder Disabilities.
Ruth Jackson, M.D., and Margaret Watkins, M.D., Dallas, Texas.
Discussion: Arthur G. Davis, M.D., Erie, Pennsylvania;
Arthur Steindler, M.D., Iowa City, Iowa.
Aseptic Necrosis of the Femoral Head.
Joseph M. Regan, M.D. (by invitation), and Ralph K. Ghormley, M.D., Rochester, Minnesota.
Discussion: William Cooper, M.D., New York, N. Y.;
Dallas B. Phemister, M.D., Chicago, Illinois.
Early Effects of Partial Denervation of the Hip for Relief of Pain in Chronic Arthritis of the Hip.
Benjamin E. Obletz, M.D., Buffalo, New York.
Discussion: Emanuel B. Kaplan, M.D., Bronx, New York;
J. Albert Key, M.D., St. Louis, Missouri.
Hamstring-Tendon Transplantation for the Relief of Quadriceps Paralysis in Residual Poliomyelitis.
J. R. Schwartzmann, M.D. (by invitation), and C. H. Crego, Jr., M.D., St. Louis, Missouri.
Discussion: Theodore H. Vinke, M.D., Cincinnati, Ohio;
Frederick J. Fischer, M.D., Detroit, Michigan.
Traumatic Proliferations of Fibrocartilage with Ossification in the Genesis of Spondylitis Deformans and Traumatic Myositis Ossificans.
Edwin F. Hirsch, M.D., Chicago, Illinois (by invitation).
Discussion: Fremont A. Chandler, M.D., Chicago, Illinois;
C. Howard Hatcher, M.D., Chicago, Illinois (by invitation).

THURSDAY, JANUARY 29

Morning Session
The Status of Lumbosacral Fusion. An Operation of Transfacet Mortised Bone Block.
Earl D. McBride, M.D., Oklahoma City, Oklahoma.
Arthrodesis of the Spine. An Ankylosing Method Permitting Early Ambulation.
Roger Anderson, M.D., Seattle, Washington; Ivan Loughlen, M.D., Seattle, Washington (by invitation); and Pen-Chien T'ung, M.D., Nanking, China (by invitation).
The Flexion Block Fusion with Screw Fixation of Facets.
O. Anderson Engh, M.D., Washington, D. C.
Discussion: Lenox D. Baker, M.D., Durham, North Carolina;
L. Ramsay Straub, M.D., New York, N. Y.;
Austin T. Moore, M.D., Columbia, South Carolina;
Alan DeForest Smith, M.D., New York, N. Y.;
Duncan C. McKeever, M.D., Houston, Texas;
David M. Bosworth, M.D., New York, N. Y.
Acute Anterior Dislocation of the Shoulder.
Toufick Nicola, M.D., Montclair, New Jersey.
Posterior Dislocation of the Shoulder.
John C. Wilson, M.D., and Francis McKeever, M.D., Los Angeles, California.
Discussion: Harrison L. McLaughlin, M.D., New York, N. Y. (by invitation);
N. J. Giannestras, M.D., Cincinnati, Ohio;
John J. Fahey, M.D., Chicago, Illinois.
Executive Sessions were held at noon on Tuesday and on Thursday.

At the Instructional Course dinner on Saturday night, an "Information Please" program was presented which was both instructive and entertaining. On Tuesday evening, a stag smoker was held in the Red Lacquer room, which enabled all present to meet the distinguished foreign guests.

The Annual Dinner was held on Wednesday evening. The brief program included introduction of the distinguished foreign guests; the presentation of the presidential medallion was made to Dr. Rex L. Diveley by Past-President Dr. J. E. M. Thomson. At this dinner the awards for scientific exhibits and motion pictures were made as follows:

'ass I: For Originality of Presentation.

1. Harry B. Macey, M.D., Temple, Texas (Scott and White Hospital), "A Plastic Procedure for Treatment of Disabling Lymphoedema of the Extremities".
2. Garrett Pipkin, M.D., Kansas City, Missouri, "Lesions of the Plica Synovalis: An Intra-Articular Disability of the Knee".
3. W. H. McGaw, M.D., H. E. Snedden, M.D., and J. M. Muckley, M.D., Cleveland, Ohio, "Pneumarthrograms of the Knee: A Diagnostic Aid in Internal Derangements".

Class II: For Scientific Value.

1. George Gennett, M.D., and Anthony F. De Palma, M.D., Philadelphia, Pennsylvania (Jefferson Medical College, Departments of Anatomy and Orthopaedics), "The Variational Anatomy of the Shoulder Joint, Especially of the Labrium Glenoidale, the Glenohumeral Ligaments, and the Associated Bursae".
2. Paul R. Lipscomb, M.D.; A. M. McKelvie, M.D.; A. C. Walsh, M.D.; and J. D. Barger, M.D., Rochester, Minnesota (Mayo Clinic), "Histologic Demonstration of Alkaline Phosphatase in Relation to Osteogenesis".
3. Leonard F. Bush, M.D.; William H. Von Lackum, M.D.; C. Zent Garber, M.D.; and James P. Miller, M.D., New York, N. Y. (New York Orthopaedic Hospital), "Bone Bank".

Class III: For Clinical Value.

1. John R. Cobb, M.D., New York, N. Y. (Hospital for Special Surgery), "Scoliosis: A Study of the Mechanical Principles in Idiopathic Scoliosis".
2. Vernon L. Hart, M.D., and Wesley H. Burnham, Minneapolis, Minnesota, "The Relationship Between Congenital Subluxation and Congenital Dislocation of the Hip".
3. David Goldberg, M.D., Springfield, Massachusetts, "Metacarpal Fractures: A New Instrument for the Maintenance of Position after Reduction".

Awards: Gadget Exhibit.

1. Howard B. Shorbe, M.D., Oklahoma City, Oklahoma (McBride Clinic): Convex Saddle Frame for Spine Operations.
2. Homer H. Stryker, Kalamazoo, Michigan: Oscillating Bone Saw.
3. Fremont A. Chandler, Chicago, Illinois (Research and Educational Hospitals):
   1. *a.* Skin Resection and Traction Cast.
      b. Negative Pressure.
   2. Leg Elevation.
   3. Drill.
   4. Retractor.
   5. Anaesthetic Pads for Spinal Operations.

Prizes were awarded to the following men, whose motion-picture productions appeared on the Audio-Visual Program:

Gold Medal—Harry B. Macey, "A Plastic Procedure for Treatment of Disabling Lymphoedema of the Extremities".

Certificate of Merit—Professor H. J. Seddon and A. E. Barclay, "Cineradiography of Abnormal Joints".

Certificate of Merit—J. A. Leo Walker, "Fusion of the Ankle Joint".

Honorable Mention—Joseph E. Markee, "The Anatomy of the Plantar Aspect of the Foot".

Honorable Mention—Alejandro Velasco Zimbron and Alberto Palacio Gomez, "Osteosynthesis of Fracture of the Neck of Femur by Pegging with Fibular Bone Splints".

At this dinner diplomas were presented to the following newly elected Fellows by President Rex L. Diveley and Dr. J. Warren White, Chairman of the Membership Committee.

Stanley Sisco Atkins, M.D., Asheville, North Carolina
Robert G. Brashear, M.D., Knoxville, Tennessee
John R. Buchanan, M.D., Youngstown, Ohio
Felix L. Butte, M.D., Dallas, Texas
James J. Callahan, M.D., Chicago, Illinois
Alfred V. Cherry, M.D., Buffalo, N. Y.
James H. Cherry, Asheville, North Carolina
Mark B. Coventry, M.D., Rochester, Minnesota
Patrick C. Doran, M.D., Akron, Ohio
Paul H. Dubé, M.D., Lakewood, Ohio

Daniel B. Eck, M.D., East Orange, New Jersey
Charles L. Farrington, M.D., St. Petersburg, Florida
George G. Fox, M.D., Meriden, Connecticut
Morris S. Friedman, M.D., South Bend, Indiana
Joseph D. Godfrey, M.D., Buffalo, New York
Meyer Zachary Goldner, M.D., Minneapolis, Minnesota
Irvin E. Hendryson, M.D., Denver, Colorado
Alan B. Hirschtick, M.D., Chicago, Illinois
Irwin B. Horwitz, M.D., St. Louis, Missouri
Louis W. Jones, M.D., Wilkes-Barre, Pennsylvania
Graham A. Kernwein, M.D., Minot, North Dakota
Byron B. King, M.D., Benton Harbor, Michigan
Joseph C. Lawrence, M.D., Evansville, Indiana
Louis J. Levy, M.D., Fort Worth, Texas
F. O. McGehee, M.D., Houston, Texas
John G. Manning, M.D., Pasadena, California
Carl D. Martz, M.D., Indianapolis, Indiana
John L. Marxer, M.D., Portland, Oregon
Matthew Mendelsohn, M.D., Washington, D. C.
Benjamin S. Meyer, M.D., Birmingham, Alabama
James Walter Miller, M.D., Seattle, Washington
Moore Moore, Jr., M.D., Memphis, Tennessee
Roy I. Peck, M.D., Philadelphia, Pennsylvania
William S. Perham, M.D., New Haven, Connecticut
Robert B. Portis, M.D., Beverly Hills, California
Frederic W. Rhinelander, M.D., San Francisco, California
Albert H. Rodi, M.D., Los Angeles, California
Myron G. Rosenbaum, M.D., Albuquerque, New Mexico
Olav Rostrup, M.D., Edmonton, Alberta, Canada
Francis B. Roth, M.D., New York, N. Y.
Carter R. Rowe, M.D., Boston, Massachusetts
Ralph E. Rowen, M.D., Little Rock, Arkansas
Americo Savastano, M.D., Providence, Rhode Island
Louis Scheman, M.D., Chicago, Illinois
Lee C. Schlesinger, M.D., New Orleans, Louisiana
William J. Schnute, M.D., Chicago, Illinois
Harold Seidenstein, M.D., New York, N. Y.
Frank B. Smith, M.D., Portland, Oregon
William F. Stanek, Jr., M.D., Denver, Colorado
John B. Stevens, M.D., Syracuse, N. Y.
Lee Ramsay Straub, M.D., New York, N. Y.
David R. Telson, M.D., Brooklyn, N. Y.
Arthur A. Thibodeau, M.D., Boston, Massachusetts
Albert A. Tisdale, M.D., Austin, Texas
William J. Tobin, M.D., Washington, D. C.
Henry F. Ullrich, M.D., Baltimore, Maryland
Francis P. Walsh, M.D., Detroit, Michigan
Edgar H. White, M.D., Cincinnati, Ohio
Edward M. Winant, M.D., New York, N. Y.

It was announced that the following had been elected to Corresponding Membership:
A. Montagne, M.D., Lima, Peru
Harry Romney, M.D., Havana, Cuba
Vaclav Tosovsky, M.D., Sokolska, Czechoslovakia
Jaroslav Slavik, M.D. Italska, Czechoslovakia
Jan Cervenansky, M.D., Bratislavia, Czechoslovakia
Med A. Monberg, M.D., Copenhagen, Denmark

The following were elected to Honorary Membership:
H. Osmond Clarke, F.R.C.S., London, England
Murray Copeland, M.D., Washington, D. C.

The following members were transferred to Emeritus Membership:
Alfred Leslie Craig, M.D., Honolulu, Hawaii

John Dunlop, M.D., Pasadena, California
Alonzo Myers, M.D., Charlotte, North Carolina

The officers of the Academy for 1948 are:

President: Myron O. Henry, M.D., Minneapolis, Minnesota
President-Elect: Mather Cleveland, M.D., New York, N. Y.
Vice-President: Allen F. Voshell, M.D., Baltimore, Maryland
Secretary: Harold B. Boyd, M.D., Memphis, Tennessee
Treasurer: Fremont A. Chandler, M.D., Chicago, Illinois
Librarian-Historian: Edward L. Compere, M.D., Chicago, Illinois.

The Sixteenth Annual Convention will be held at the Palmer House, Chicago, January 22–27, 1949, under the presidency of Dr. Myron O. Henry.

SUGGESTED PLANS FOR BETTER COOPERATION OF ORGANIZATIONS CONCERNED WITH APPROVAL OF RESIDENT TRAINING PROGRAMS

BY GUY A. CALDWELL, M.D., NEW ORLEANS, LOUISIANA*

All organizations concerned with graduate training realize a need for closer coordination of their activities. The American College of Surgeons, the Council on Medical Education and Hospitals of the American Medical Association, and the specialty boards are most directly concerned with inspections and approval of services for specialty training. Each of these is interested in providing the best possible graduate training in the specialties and, in general, they have similar standards and requirements specified for the hospitals and their staffs to meet. However, as the scope of activity of the various organizations has broadened, there have developed some overlapping and duplication of efforts. Some hospital services have been inspected by a representative of the American College of Surgeons and subsequently by someone from the Council on Medical Education and Hospitals. Sometimes the opinions of the two inspectors have differed, and the lists of approved services which were published, one by the American College of Surgeons and the other by the American Medical Association, therefore, have not always been uniform. Some residencies approved by the College were not recognized by the Council, and *vice versa*, all of which has been confusing to prospective trainees and embarrassing to the certifying boards.

The number of approved services has increased rapidly during the past three years, and many of them were approved only on a temporary basis. Therefore, at this time, there is need for review or reinspection of nearly all recognized services. So few qualified inspectors are available to the Council and College, that it may be several years before all the needed inspections can be completed. Under these conditions, the American Board of Surgery and the Joint Committee on Graduate Education of The American Academy of Orthopaedic Surgeons and The American Orthopaedic Association obtained the consent of the Council on Medical Education and Hospitals to have some of their own diplomates visit hospitals with tentatively approved services and make reports on the present status of these services.

By sending out a large number of qualified men simultaneously, these two boards obtained a nationwide survey of the training in surgery and orthopaedic surgery in a few months' time. Reports made by these diplomates, acting as inspectors, were of special interest to the Council because, for the first time, the reports were made by men capable of judging the quality of surgery performed, the teaching ability of the staff, and the effectiveness of the training program from the viewpoint of the residents.

As a result of the efforts made by the Joint Committee on Graduate Education and the American Board of Surgery, a meeting was held in Chicago, on February 21, of the Council on Medical Education and Hospitals, the trustees of the American Medical Association, a committee of regents of the American College of Surgeons, the secretary of the Medical Advisory Board, and representatives of the American Boards of Surgery and Orthopaedic Surgery. The purpose of the meeting was to set up uniform standards, to eliminate duplication of effort and expenditure of funds, to pool the reports of inspections, and to make the resultant information available to all parties concerned.

An excellent spirit of cooperation was manifested by all present and the meeting culminated in the designation of a committee of seven, representing all the related organizations, who are to formulate recommendations and working plans for a unified service and common standards. Their plans will also provide for more frequent and competent inspections of resident-training services, and should eliminate conflicting reports and lists.

Orthopaedic surgeons may be interested to know that much of this constructive movement has been the outgrowth of the excellent work of the Joint Committee on Graduate Training. The reports of the early work and inspections done by this Committee three years ago have led to the recent surveys and widespread interest in future planning.

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* President of the American Board of Orthopaedic Surgery.

Book Reviews

Chronic Structural Low Backache Due to Low-Back Structural Derangement. R. A. Roberts, B.Sc., M.B., Ch.B., D.M.R.E. London, H. K. Lewis and Co., Ltd., 1947. 45 shillings.

Under this descriptive but awkward title, the author discusses the various developmental defects of the lower back as etiological factors in the production of low-back pain and sciatic pain. The studies upon which the work is based were made mostly in a temporary base hospital, serving the Middle East Forces. This accounts for the imperfections in reproduction of many of the roentgenographic illustrations, but the author has made tracings of the original films which demonstrate the defects discussed.

Case histories are presented in the discussions of the different defects, and the importance of tracing the histories back to childhood is emphasized, as most of them divulge recurring attacks of back disability over a period of many years.

The theory is advanced that the bone defect of the pars interarticularis of the neural arch, known also as spondylolysis and separate neural arch, is not a defect of ossification of that part, but rather a linear de-ossification due to overstrain from the upright posture, with consequent changes in the soft parts similar to those occurring in so-called march fractures. The author describes a softening with downward and forward sagging of the arch, with roentgenographic appearance of a translucent striation across it. He mentions the possibility of re-ossification of the part with formation of an S curve in the bone.

Readers who have examined a number of macerated specimens of this defect, particularly the unilateral ones, and have noted the facility with which march fractures heal, will hesitate to accept this theory.

Supernumerary ossicles which cause widening of the pars interarticularis of the upper lumbar vertebrae are thought to represent bridging of the de-ossification defects. In the illustrations they suggest irregular calcifications of the interspinal ligaments. Defects in ossification of the articular processes are mentioned as of frequent occurrence and of major clinical importance. The various types are well illustrated.

Diminished intervertebral space is considered a frequent cause of back pain, particularly when accompanied by sclerosis and lipping of the adjacent vertebral bodies, which suggest prolonged mechanical irritation.

In Chapter VIII are discussed backaches without recognizable roentgenographic changes. These are often associated with genito-urinary, psychiatric, rheumatic, or gastro-intestinal disturbances. It is argued that often such disturbances are the result, rather than the cause, of mechanical overstrains and soft-tissue abnormalities of the back, with involvement of nearby sympathetic ganglia.

The author concludes that structural derangements of the back give rise to backache only as they affect stability of the part, thereby throwing excessive strain on the ligaments and muscles with consequent oedema, exudation, adhesions, and contractures.

Treatment of backache due to structural defects is predicated on the assumption that the ache is the result of mechanical strain, consequent upon the upright posture. The first objective is, therefore, reduction of this strain by flexion and balancing of the lumbar curve, and the restoration of tone to the muscles that maintain it. Temporary support, exercises, and occasionally manipulation to free adhesions are the principal suggestions. When there is definite evidence of permanent instability or when disability is progressive, surgical stabilization of the part is indicated.

Two operative procedures are mentioned,—the bone-graft fusion and Dandy's curettage of the intervertebral disc. Since Dandy's discussion of spondylolisthesis was based on Neugebauer's essay on that subject, *published in 1892, it has not won much credence.*

In the closing chapter, the frequency of the faulty diagnosis of malingering is stressed and case histories are presented, showing the injustice done many individuals through failure to study each patient thoroughly. Actual malingering is rarely found, if a careful study is carried out.

British Surgical Practice. Volume I. Edited by Sir Ernest Rock Carling, F.R.C.S., F.R.C.P., and J. Paterson Ross, M.S., F.R.C.S. London, Butterworth and Co., Ltd., 60 shillings (25 pounds for the set); St. Louis, C. V. Mosby Company, 1947. $15.00 ($125.00 for the set).

British Surgical Practice comprises a series of eight volumes, plus an index, dealing with surgical diagnosis and surgical technique. Volume I is now available, Volume II will be ready very soon, and the remaining volumes are scheduled for release during 1948 and 1949. The completed set is expected to contain from 4,200 to 5,000 pages.

The subject matter, which covers the field of surgical practice, is arranged alphabetically, so that Volume I begins with Abdominal Emergencies and concludes with the Autonomic Nervous System. A long list of eminent surgeons have contributed to Volume I. In general, the articles are classified as to etiology, surgical

and morbid anatomy, the clinical picture, differential diagnosis, treatment, and results of treatment. Each volume has an index; upon completion of the set, an analytical index will be published as a separate volume.

In order that the set may be kept up to date, an annual supplement will be published, correlated with the original volumes by a key number.

A Manual of Fractures and Dislocations. Ed. 2. Barbara Bartlett Stimson, A.B., M.D., Med. Sc.D., F.A.C.S. Philadelphia, Lea and Febiger, 1947. $3.25.

The second edition of this handbook on the diagnosis and treatment of fractures and dislocations is written in a concise and practical manner, and is useful for medical students and practitioners who do not specialize in the treatment of these injuries. The author's experience has been broad, as, for many years, she has been associated with a large teaching fracture service in New York City; she bases her opinions on the records of more than 21,000 fractures and dislocations, many of which she herself has observed and treated. The author admits that there are frequently many ways to treat the individual fracture, but she has selected, by and large, those methods which, in the experience of the fracture clinic of the Presbyterian Hospital-Columbia Medical Center, have proved most effective.

A few points should be questioned. The illustration of Russell traction does not appear to be quite correct; internal fixation of fractures does not necessarily shorten the period of external fixation; internal fixation does not speed healing of fractures,—rather, in some cases it may retard healing. There is no real substitute for callus. The pillow and sideboard splint should be advocated for the temporary splinting of fractures below the knee.

The chapters on the healing of bone and on the principles of fracture treatment are particularly worth while, and can be read with benefit by all interested in the management of fractures and dislocations.

Minor Surgery. Ed. 6. Frederick Christopher, B.S., M.D., F.A.C.S. Philadelphia, W. B. Saunders Company, 1948. $12.00.

The latest edition of this textbook presents a thorough revision of that published in 1944; many sections have been rewritten and new sections have been added. Increasing importance is ascribed to the sulfonamides and to antibiotics, and information gained from experience in World War II has been incorporated in the discussions of such subjects as burns, varicose veins, and artificial respiration. The sections on wound healing, fractures of the carpal scaphoid, Colles's fracture, march fractures, skin-grafting, and others, have been amplified.

The final chapter, "The Surgical Intern", contains much practical information and has long been a useful guide for interns. Each chapter closes with an extensive bibliography.

In its scope of subject matter, this continues to be one of the foremost surgical texts for students, interns, and general practitioners. The field of minor surgery is vast and always increasing.

Diseases of the Joints and Rheumatism. Kenneth Stone, D.M. (Oxon.), M.R.C.P. London, William Heinemann, Ltd.; New York, Grune and Stratton, 1947. $6.50.

Anyone interested in the diseases of the joints and rheumatism would do well to peruse in a careful manner this book by Kenneth Stone. It contains a great deal of information, interestingly presented.

The chapter on "General Anatomy and Physiology of the Joints" is well done. It does, however, lack complete information concerning synovial fluid,—particularly the interpretation of variations in cellular and chemical findings.

The author uses in an effective style the original descriptions by many early writers. This gives one the impression that the work was studiously compiled.

All medical orthopaedists and orthopaedic surgeons should read Chapter IV, "Rest and Movement". One may not agree with all that Stone says, but the fundamental therapeutic principle is correct. Its application is the thing to learn.

A lack of close association and exchange of ideas between the medical orthopaedists and the orthopaedic surgeons tends to delay the diffusion of knowledge; this is obvious in the chapter on "Painful Hips". No mention is made of mold arthroplasty as a method of relieving the pain in these conditions.

The concept and use of the terms "rheumatism" and "fibrositis" is presented clearly, and perusal of the book gives a better understanding and a little more confidence to the physician who confronts a patient complaining of rheumatism.

Regional Orthopaedic Surgery and Fundamental Orthopaedic Problems. The American Academy of Orthopaedic Surgeons. James E. M. Thomson, M.D., Editor. Ann Arbor, Michigan, J. W. Edwards, 1947. $6.00.

This volume of lectures given during the Instructional Courses of The American Academy of Orthopaedic Surgeons, in January 1946, differs from the first two volumes in that it is directed toward the problems of

civilian orthopaedic surgery rather than toward those arising from war. Thirteen courses of lectures are included. The regions of the foot and ankle, the hip, and the shoulder are presented, with consideration of their anatomy and of the diagnosis and treatment of associated pathological conditions. Other lectures concern fractures, x-ray interpretation, poliomyelitis, cerebral palsy, physiology, club-foot, and posture.

A distinguished group of surgeons contributed to this work. The volume is well prepared, and the illustrations are lavish in number and of excellent quality. The lectures represent a fundamental approach to the problems of orthopaedic surgery; they are of great value to students, teachers, and practitioners of orthopaedic surgery.

American Medical Research Past and Present. Richard H. Shryock, Ph.D. New York, The Commonwealth Fund, 1947. $2.50.

This authoritative and compact summary (325 pages) of a very large and cumbersome subject is sponsored by the Committee on Medicine and the Changing Order, established in 1942 by the New York Academy of Medicine. It is one of a series of monographs "designed to provide the framework for an understanding of the current medical situation and its trends. Contemporary medicine is treated as a product of evolution. Richard H. Shryock is Professor of American History and Lecturer on Medical History at the University of Pennsylvania. He wrote "Development of Modern Medicine" in 1936, and is the author of various articles in the field of medical history.

The book has probably greatest value in its brilliant treatment of the early scientific and cultural influences upon research in America up to the modern age of philanthropic, industrial, and governmental support of research. British, French, and German periods of influence are traced. It is no doubt impossible for anyone to gain a proper perspective of modern trends at this early date after the second World War. Speculations are influenced by unusual modern trends, as illustrated by a statement originating from A. N. Richards "Actually, a $2,000,000,000 Manhattan Project on cancer—where the basic leads are not yet clear—would probably only waste large sums of money, if it did not do more positive damage." That the issues are even today not yet clear is suggested by the plaintive remark at the end of the book: "The research worker who considers historical perspective a waste of time, who assumes that nothing was done in his field until the last century or even the last decade, and who is indifferent to the larger outcomes, is on much the same level as those laymen who dismiss all research that is not 'practical'."

That the value of basic research is still in doubt, in spite of such notable examples as the great German discoveries of the latter half of the last century, is remarkable. The time lag between basic discovery (original thought) and application in diagnosis or therapy has been enormous; it is not always the result of blindness lack of potentialities, but may rather be due to lack of knowledge of related fields, necessary to assimilate the implications of the discovery. The author has very properly submerged the contribution of American research, compared to that of other countries, in the description of the whole trend, for medical research transcends international boundaries. In spite of some fundamental American discoveries, one is left with the idea that our contributions have been largely technological. Examples are the development of the use of the sulfonamides, penicillin, and the electron microscope. One hopes that the author some day will develop the theme of what circumstances—historical, environmental, cultural, financial, or legislative—are the most favorable for the development of important discoveries in medical sciences.

The general physician or specialist who has a personal interest in gaining perspective in the growth of medical ideas and introducing himself to current trends will find that this book will give him an excellent introductory course. The references will suggest further reading. For the rest, it will appeal, as John F. Fulton suggests in the Preface, to those actually engaged in medical research, teaching, or medical administration. Those who dispense funds for research should find it of essential importance. It is not easy or popular reading, but it deserves careful, meticulous study.

Sports for the Handicapped. Ed. 2. George T. Stafford, Ed.D. New York, Prentice-Hall, Inc., 1947. $5.00.

This concise text of 334 pages by a well-recognized Professor of Physical Education brings to interested readers a mass of material and experience, largely taken from the reconditioning program of the Army hospitals. It emphasizes the importance of physical recreation for those patients convalescing from severe permanent disabilities.

As a ready reference for workers interested in physical medicine, physiotherapy, and occupational therapy, it should serve as a useful manual and guide; and for those physical educators interested in remedial exercises for the physically handicapped, it should fill a place of major importance. For the orthopaedic surgeon and those in allied fields of medicine, the descriptive medical material pertaining to specific disease or injury is not entirely up-to-date.

On the whole, however, from the point of view of the permanently disabled and their later convalescent treatment, this book will provide trained workers in physiotherapy and occupational therapy with a guide widening the horizon of recreational activities adaptable to the severely handicapped.